LAND DEGRADATION & DEVELOPMENT
Land Degrad. Develop. (2012)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ldr.2164

ASSESSING THE IMPACT OF THE SLOPING LAND CONVERSION PROGRAMME ON RURAL SUSTAINABILITY IN GUYUAN, WESTERN CHINA

H. J. KÖNIG[1,3]*, L. ZHEN[2], K. HELMING[1], S. UTHES[1], L. YANG[2†], X. CAO[2] AND H. WIGGERING[1,3]

[1]*Leibniz-Centre for Agricultural Landscape Research (ZALF) e.V., Eberswalder Straße 84, 15374 Müncheberg, Germany*
[2]*Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A, Datun Road, Chaoyang District, Beijing, 100101 PR China*
[3]*Institute of Earth and Environmental Science, University of Potsdam, Karl-Liebknecht-Str. 24–25, 14476 Potsdam-Golm, Germany*

Received: 13 July 2011; Revised: 8 March 2012; Accepted: 5 April 2012

ABSTRACT

The goal of China's sloping land conversion programme (SLCP) is to combat soil erosion and to reduce rural poverty. An ex-ante assessment of possible SLCP impacts was conducted with a focus on rural sustainability, taking the drought-prone region of Guyuan in Western China as an example. The Framework for Participatory Impact Assessment (FoPIA) was used to conduct two complementary impact assessments, one assessing SLCP impacts at regional level and a second one assessing alternative forest management options, to explore possible trade-offs among the economic, social and environmental dimensions of sustainability. Regional stakeholders assessed the SLCP to be capable of reducing soil erosion but felt it negatively affected rural employment, and a further continuation of the Programme was advocated. Assessment of three forest management scenarios by scientists showed that an orientation towards energy forests is potentially beneficial to all three sustainability dimensions. Ecological forests had disproportionate positive impacts on environmental functions and adverse impact on the other two sustainability dimensions. Economic forests were assessed to serve primarily the economic and social sustainability dimensions, while environmental impacts were still tolerable. The FoPIA results were evaluated against the available literature on the SLCP. Overall, the assessment results appeared to be reasonable, but the results of the regional stakeholders appeared to be too optimistic compared with the more critical assessment of the scientists. The SLCP seems to have the potential to tackle soil erosion but requires integrated forest management to minimize the risk of water stress while contributing to economic and social benefits in Guyuan. Copyright © 2012 John Wiley & Sons, Ltd.

KEYWORDS: land conversion; land use; afforestation; land use functions; Grain for Green Project; ex-ante impact assessment; sustainable development; stakeholder participation

INTRODUCTION

The remote and less-developed region of Guyuan in Western China is threatened by vast soil erosion and land degradation problems due to fragile soils, droughts and increasing consumption of natural resources by a growing population. The impact of land conversion programmes on rural sustainability in such a problematic area is of particular interest, the information has the potential to help avoid a further worsening of undesired development trends.

In 1999, the Chinese government initiated the nationwide sloping land conversion programme (SLCP), also known as the 'Grain for Green Project' to tackle this problem (Xu *et al*., 2004). The programme was implemented by converting crop production on erosion prone land with steep slopes into forests and grassland in large parts of the upper Yellow and the Yangtze River basins (Xu *et al*., 2006). Besides having the major goal of reducing land degradation, the SLCP also aimed at alleviating rural poverty and at stimulating economic development in rural regions (Bennett, 2008; Grosjean and Kontoleon, 2009). Cropland on slopes steeper than 25 degrees was intended to be converted into 'ecological forests' (with primary ecological functions) and grassland, whereas cropland on slopes between 15 and 25 degrees was intended to be converted into 'economic forests' or grassland including fruit orchards and timber plantations (Weyerhaeuser *et al*., 2005; Ye *et al*., 2003). Between 2000 and 2009, 4·8 per cent of the cropland was been converted into forest land in Guyuan, according to regional experts. Between 2010 and 2016, an additional 3·4 per cent of cropland will be retired and used for afforestation purposes.

Farmers affected by the programme are supposed to receive compensation as cash (300 Yuan per ha) and grains (1500 kg per ha) (Bennett, 2008). Financial compensation is provided for varying duration, depending on the type of conversion: 2 years for conversion into grassland, 5 years for conversion into economic forests, and for a maximum 8 years for conversion into ecological forests.

The SLCP has widely been recognized as being effective in terms of land conversion efforts with a total size of

*Correspondence to: H. J. König, Leibniz-Centre for Agricultural Landscape Research (ZALF) e.V., Eberswalder Straße 84, D-15374 Müncheberg, Germany.
E-mail: hkoenig@zalf.de
†Present address: Beijing Tsinghua Urban Planning & Design Institute, Environmental & Infrastructural Division, 1A, East Qinghe Jiayuan, Beijing 100085, China

146 000 square kilometres of cropland being converted at national level between 1999 and 2010 (Yin and Yin, 2010). Several studies have attempted to evaluate the SLCP, for example, related to food security issues (e.g., Feng *et al.*, 2005; Peng *et al.*, 2007; Xu *et al.*, 2006; Yang, 2004), soil properties (e.g., Cao *et al.*, 2007; Chen *et al.*, 2007b; Zhang *et al.*, 2010), water balance (e.g., Chen *et al.*, 2007a; Gates *et al.*, 2011; Huang and Pang, 2011; Sun *et al.*, 2006) as well as aspects of programme implementation, participation and effectiveness (e.g., Bennett, 2008; Uchida *et al.*, 2007; Xu *et al.*, 2004; Yin and Yin, 2010). In summary, most available SLCP impact studies looked at economic and social aspects, whereas few studies investigated environmental impacts (this might be reasonable because quantitative data related to forest ecology require long-term monitoring systems). However, none of these studies have integrated all dimensions of sustainability yet, nor have they adequately the ex-ante impacts of the SLCP at aggregated level.

In this study, an attempt is made to combine regional stakeholder knowledge with scientific expertise in order to conduct a more comprehensive and reflected impact assessment study. Stakeholder participation in environmental studies can be used, for example, to integrate local knowledge (Stringer and Reed, 2007; Vogt *et al.*, 2011) and to consider different perceptions of stakeholders (Reed *et al.*, 2007; Schwilch *et al.*, 2011). A previous study of König (2010) explored possible contributions of alternative forest management scenarios to regional sustainability. The study had an isolated view of the forestry sector, while in this study the focus was on impacts of different SLCP implementation options (conversion of cropland into forests) on regional sustainability covering all land use sectors. Findings from König *et al.* (2010) are used to study the regional impacts of the SLCP implementation as well as possible consequences of alternative forest management. Subsequently, results from both assessments are discussed in a complementary way. The aim of this study therefore was to conduct a comprehensive ex-ante impact assessment of the SLCP covering the economic, social and environmental dimensions of sustainability. The results of the Framework for Participatory Impact Assessment (FoPIA) were evaluated under consideration of the available scientific literature on the SLCP reviewed.

MATERIALS AND METHODS

Study Area

The case study region of Guyuan is located in the centre of the Loess Plateau in the southern part of the Hui autonomous region of Ningxia (Figure 1). The main regional problems are harsh environmental conditions, land degradation and low economic development (Zhen *et al.*, 2009a;

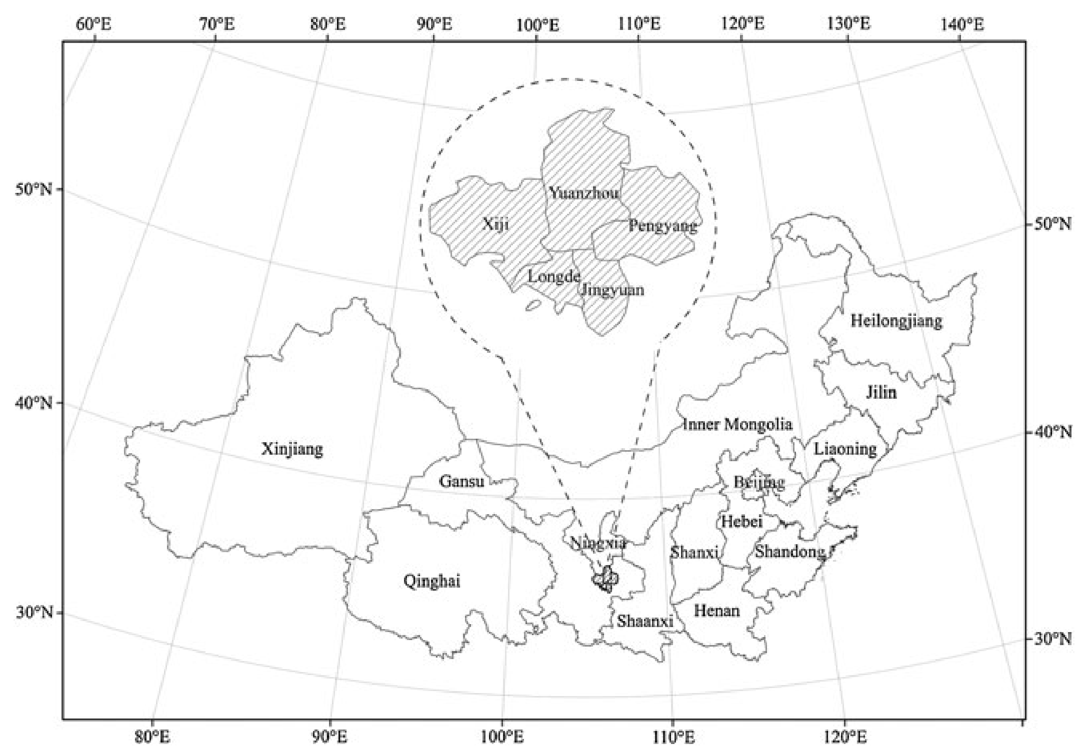

Figure 1. Location map of the study area of Guyuan, China.

Zhu *et al.*, 1986). The climate is semi-arid with cold, dry winters and hot, wet summers. The average annual rainfall is 470 mm with regional variability. The terrain is mountainous with elevations ranging from 1248 to 2942 m a.s.l.

The main land use activities are smallholder subsistence agriculture and livestock husbandry with an average farm size of 4·6 mu (15 mu = 1 ha) per family household. In 2009, the rural farm household activities were typically 61 per cent on-farm activities, such as cropping (50 per cent), livestock breeding (11 per cent), off-farm work (37 per cent) and other activities (2 per cent). Agriculture is rainfed, and the major crops include maize, wheat, potato, millet, oilseeds and several legume species (Zhen *et al.*, 2009a). The livestock includes sheep, goats, beef cattle, dairy cows, pigs and poultry. The remaining natural vegetation includes wild grassland and shrubs that grow mainly on the steep slopes where human activities are restricted (Chen *et al.*, 2001).

Poor economic development is considered a major constraint for development in Guyuan where there is a low GDP per capita of RMB 8470, which was only 29 per cent of the Chinese national average of RMB 29 992 in 2010. The average income per rural households was RMB 3477, which is 59 per cent of the national average of RMB 5919 in 2010. With the SLCP, Guyuan follows a model centred on environmental priority where economic development comes only as a second goal (Zhen *et al.*, 2009b).

General Impact Assessment Approach

An approach for structuring the impact assessment of land use changes while equally covering the three sustainability dimensions (economic, social, environmental) is proposed by Helming *et al.* (2011) making use of so-called land use functions (LUFs) as developed by Pérez-Soba *et al.* (2008). This framework appeared to be suitable for Guyuan and was therefore adopted for this study, but it proved to be challenging to quantify the impact of alternative land use scenarios, such as land conversion as in the case of the SLCP, on the LUFs. Ideally, impacts on LUFs would be derived from a combination of (i) ex-post analysis of monitoring data; (ii) ex-ante simulation experiments, for example, as in the case of the Sustainability Impact Assessment Tool (Sieber *et al.*, 2008; Uthes *et al.*, 2010); and (iii) participatory expert-based tools (Morris *et al.*, 2011) to also consider stakeholder perceptions and expert knowledge. A thorough literature survey should accompany all three steps to ensure they are up-to-date and allow for validation.

However, as in many cases in developing and transition countries, lack of data prevented the first two types of analysis (Reidsma *et al.*, 2011). Area-wide, spatially explicit monitoring data of the SLCP implementation in Guyuan did not exist. Some unofficial paper-based reports were found, but their reliability is unclear, reporting high tree survival rates of 80 to 90 per cent. Personnel from the responsible government agencies disclosed that dead trees were simply replaced by new seedlings, without actually reporting this. Field visits were limited to demonstration sites and therefore not representative. Other studies circumvented such dificulties by surveying SLCP participants (e.g., Uchida *et al.*, 2005; Xu *et al.*, 2004; Yang, 2004). Participants' answers are a common source of information, but their reliability is unclear, particularly because farmers usually have a sector-specific view and are often less well educated, therefore less likely to be capable of performing sustainability assessments, and involuntary participation is a frequently observed phenomenon (Grosjean and Kontoleon, 2009).

The FoPIA Approach

To assess programme effects at an aggregated regional scale, it appeared to be more promising to take the road of a participatory expert-based approach to analysis, by making use of the FoPIA (Morris *et al.*, 2011). The FoPIA comprises a preparation phase and an expert workshop, which follows a structured sequence of assessment steps, including (i) interactive development of regional land use scenarios; (ii) specification of the sustainability context; and (iii) expert-based assessment of scenario impacts and analysis of possible trade-offs among the economic, social and environmental sustainability dimensions. An after-workshop evaluation phase is used to further analyze and document workshop results.

The approach benefits from a diverse group composition, as only then, a variety of different views can be considered, but group diversity also adversely affects scenario complexity. For example, a heterogeneous group can usually handle relatively simple scenarios because the group members will feel capable of assessing them. On-the-other-hand, because of the variety of views considered, an aggregated assessment, for example, at the level of sustainability, is more likely to achieve succcess with such a group. In contrast, a more homogenous group, for example, experts in one field, will be able to deal with complex scenario assumptions; results, however, will likely remain at the level of the disciplines involved and therefore not allow for overall conclusions on sustainability.

Given the aforementioned issues, we decided to follow a two-step approach. A first FoPIA workshop was held in 2009 in Guyuan with a heterogeneous group of regional experts SLCP (from now on referred to as 'regional group') to assess the impact of SLCP land conversion on sustainability at the regional level, with the use of relatively simple scenario assumptions. A second FoPIA workshop was held at the Chinese Academy of Science in Beijing in 2010 with a relatively homogenous group of scientists from different national research institutes to assess the impact of more complex scenarios focusing on alternative SLCP forest management options (from now on referred to as 'forest group'). Work from the second workshop has been published in a previous article by König (2010), but this study had an isolated view on the forestry sector and did not consider SLCP impacts on regional sustainability.

Workshop Participants

The regional group was directly consulted in Guyuan and included ten experts from the Bureau of Environmental Protection, Development and Reform Commission, Guyuan Agriculture Research Institute, Bureau of Forestry, Department of Regional Water Management, Bureau of Agriculture and Animal Husbandry and Bureau of Land Resource Management. The workshop was part of a longer field trip and was accompanied by a household survey in three villages and a participatory rural appraisal in one village.

For the forest group, ten researchers with a specific knowledge about the regional conditions in Guyuan and specific expertise on the SLCP were invited to participate in an expert workshop, including scientists from the Chinese Academy of Forestry (CAF), the Department of Natural Geography (IGSNRR, CAS), the Department of Human Geography (IGSNRR, CAS), the Department of Natural Resources and Environmental Security (IGSNRR, CAS) and the Chinese Academy of Social Sciences (CASS).

Expert-developed Scenarios

Scenario narratives were drafted by the research team, on the basis of available data and figures, and presented to the regional group and the forest group for discussion, respectively. Scenario assumptions were elaborated together with the group participants considering implicit knowledge and to ensure a commonly understood and accepted set of scenarios (Table I). In the regional group, three scenarios were assessed, including two SLCP implementation scenarios [first phase of the implementation between 2000 and 2009 (S2), and a second implementation phase between 2010 and 2016 (S3)] and a reference scenario (S1) that served as a counterfactual to assess impacts in the absence of the SLCP (continuation of crop production) (Table I). The forest group assessed the impact of three alternative forest management scenarios, including an economic-forest (F1), an ecological-forest (F2) and an energy forest management (F3) scenario (Table I). Land use sectors included agriculture, forestry and build-up areas. The target year for all scenarios was 2020. Both workshops started with the introduction of a drafted set of scenario narratives, which were presented to the corresponding workshop participants.

Expert-based Impact Assessment

A set of nine LUFs and nine forest functions (FFs) had been developed prior to the workshop, taking the general set of LUFs from a paper by Pérez-Soba *et al*. (2008) as starting point and were introduced to the regional group and the forest group, respectively (Table II). Both sets of functions were equally balanced among the economic, social and environmental sustainability dimensions. Together with the workshop participants, each function was assigned one corresponding indicator in order to have a precise criterion for the impact assessment, for example, regional employment rate for the *provision of work* or water availability for the *provision of abiotic resources* (Table II). We decided to have only one indicator per function in order to avoid complexity and to keep the scenario assessment focused and operational during the workshops.

Subsequently, experts passed two paper-based assessment rounds on each workshop—one for assigning weights from one to nine to the different LUFs, reflecting their perceived importance, and one for assessing the impact of the different scenarios on the LUFs using a scale from −3 to +3. After each round, the assessment results were projected, discussed and re-scoring was allowed as needed, to reduce the range of assessment results. For further reading on each step of the FoPIA, see Morris *et al*. (2011).

Table I. SLCP implementation scenarios (S1, S2, S3) and forest management scenarios (F1, F2, F3)

Scenario	Scenario characteristics	Land use sectors	Relevance to Guyuan
S1: (REF)	Forest cover at 12·8%; remaining land mainly used for agriculture	All sectors	Reference scenario as without SLCP policy implementation
S2: SLCP-1	Conversion of cropland into forest land on slopes above 25 degrees; forest cover increases by 4·8% to 17·6%	All sectors	SLCP implementation between 2000 and 2009
S3: SLCP-2	Conversion of cropland into forest land on slopes between 15 degrees and 25 degrees; forest cover increases by additional 3·4% to 21%	All sectors	Further expansion of the SLCP between 2010 and 2016
F1: economic forest	Orchards for fruit plantations (e.g., apple, nuts, apricot, etc.)	Forest sector	Partially established agro-forest type at 20–25%
F2: ecological forest	Planting and maintaining trees with limited economic use to restore degraded land	Forest sector	Main forest type established under the SLCP at 70–80% in Guyuan
F3: energy forest	Use of sloped and marginal land for bio-energy production	Forest sector	Little recognition yet of less than 1%

SLCP, Sloping Land Conversion Programme; REF, reference scenario.

Table II. Land use functions, forest functions and corresponding assessment indicators

Land use functions (LUFs)	LUF indicator
ECO 1: Land-based production	Economic production from land (yield)
ECO 2: Non-land-based production	Build-up area (m^3)
ECO 3: Infrastructure	Road density and quality (network size and status)
SOC 1: Provision of work	Regional employment (%)
SOC 2: Quality of life	Net income per household (RMB)
SOC 3: Food security	Regional food availability (kg/capita)
ENV 1: Abiotic resources	Soil health/quality (status)
ENV 2: Biotic resources	Habitat and biodiversity (status)
ENV 3: Ecosystem processes	Vegetation cover (status)
Forest functions (FFs)	FF indicator
ECO 1: Wood production	Income from wood harvests (RMB)
ECO 2: Non-wood production	Income from fruit yields (RMB)
ECO 3: Industry and services	Income from forest industry and services (RMB)
SOC 1: Forest labour	Sectoral employment (%)
SOC 2: Health	Clean air (status)
SOC 3: Access to land	Right to access and utilize forest
ENV 1: Abiotic resources	Soil health/quality (status)
ENV 2: Biotic resources	Habitat and biodiversity (status)
ENV 3: Ecosystem processes	Water availability/yield (m^3)

ECO, economic; SOC, social; ENV, environmental. Forest functions and corresponding indicators are adapted from König (2010) with permission.

The assessment of the scenarios for the three sustainability dimensions is based on an aggregation of the scenario impact scores and corresponding LUF and FF weights by using the following equation:

$$wi_d = \sum_{f=1}^{n} w_{f,d} * i_{f,d} \quad (1)$$

where: wi is the weighted impact, w is the weight assigned to each function, i is the average impact for each function, d is the sustainability dimension (economic, social, environmental) and f is the function ($n = 9$).

This allows for comparison of different scenarios and a ranking of scenarios, based on which, possible implications for land use and decision support can be discussed.

Literature Survey of SLCP Impact Studies

A literature survey of SLCP impact studies was conducted on the basis of scientific databases including SCOPUS and ISI Web of Knowledge. Key words including 'sloping land conversion' and 'grain for green' were combined with topics related to the nine LUFs and nine FFs (Table II) and resulted in a list of 39 publications covering the relevant topics (Table III). Although we are aware that much has been published in Chinese, we were only able to consider articles published in English.

RESULTS AND DISCUSSION

Relative Importance of Land Use Functions

In the regional group, the economic LUF *land-based production* (8·5) was assessed to be of highest priority, as it was considered to be the major economic activity of rural people in Guyuan (Table II). Of slightly lower importance were the environmental LUFs *maintenance of ecosystem processes* (7·5) and *provision of biotic resources* (7·6), reflecting the regional vulnerability of the environment in Guyuan, prone to land degradation and losses in biodiversity. The lowest weights were assigned to the LUF *non-land-based production* (6·0), reflecting that most of the rural society in Guyuan is still employed in the agricultural sector and that opportunities for *non-land-based production* in this remote region are limited. The LUFs *food security* (7·1) and *quality of life* (7·0) were reported to be two major concerns for rural farmers in Guyuan, as agricultural production and rural livelihood were frequently affected by droughts, loss of harvests and rural poverty, respectively, and therefore received high scores. The *provision of abiotic resources* (6·5) related to soil was perceived to be a critical factor for land-based production but relatively less important than other functions. This may appear contradictory, as the SLCP has a particular focus on this aspect, but reflects that the workshop participants applied a kind of 'fairness' principle when comparing different functions. Of relatively lowest importance were the LUFs *provision of work* (6·1) and *infrastructure* (6·1).

Relative Importance of Forest Functions

In the forest group, all environmental functions were given high weights reflecting the need to reduce land degradation in Guyuan with abiotic resources (8·7), biotic resources (7·7), maintenance of ecosystem processes (9·7) (Table II). The economic function *income from wood production* (6·0) was assessed to be of lowest importance compared

Table III. Overview of land use functions (LUFs) and forest functions (FFs) covered by the impact studies (LUFs and FFs explanations can be found in Table II)

		Economic LUFs			Economic FFs			Social LUFs			Social FFs			Environmental LUFs/FFs		
Authors	Year	ECO1	ECO2	ECO3	ECO1	ECO2	ECO3	SOC1	SOC2	SOC3	SOC1	SOC2	SOC3	ENV1	ENV2	ENV3
Ye *et al*.	2003	x					x				x					
Xu *et al*.	2004	(x)						x	x							
Hong	2004									x			x			
Feng *et al*.	2005	x								x						
Uchida *et al*.	2005	x	x					x	x							
Weyerhaeuser *et al*.	2005				x	x	x				x					
Chen and Cai	2006													x		x
Edinger and Huafang	2006	x						x	x						(x)	
Long *et al*.	2006	x							x					x		
Sun *et al*.	2006	x														x
Xu *et al*.	2006	x	x		x	x		x	x							
Xu *et al*.	2006	x								x						
Zheng	2006													x		x
Cao *et al*.	2007						x					x		x		
Chen *et al*.	2007	x												x		x
Chen *et al*.	2007	x			x									x		x
McVicar *et al*.	2007	x														x
Peng *et al*.	2007	x							x	x						
Uchida *et al*.	2007	(x)						x	x							
Wang *et al*.	2007	x														
Bennett*	2008						x	x	x		x					
Cao	2008	x										x		x		x
Wang *et al*.	2008	x			x											x
Zhang et a.	2008	x														x
Cao *et al*.	2009	x		(x)			x					x		x	(x)	x
Grosjean and Kontoleon	2009						x	x	x				(x)			
He *et al*.	2009	x				x			x							
Stokes *et al*.	2009	x		(x)							x			x		x
Uchida *et al*.	2009		x					x	x							
Chen *et al*.	2009	x	x	(x)				x	x						(x)	
Dai	2010	x														
Liu *et al*.	2010	x			x	x		x	x							
Wang *et al*.	2010	x	x		x			x	x							
Yang *et al*.	2010													x	(x)	x
Yao *et al*.	2010	x	x					x	x							
Zhang *et al*.	2010													x		
Bennett *et al*.	2011						x	x	x				(x)			
Cao *et al*.	2011				x	x	x					x		x		x
Gates *et al*.	2011	x														x
Huang and Pang	2011	x			x	x								x		x
LUFs and FFs addressed (*n*)		26	6	3	8	6	8	13	16	4	4	4	4	13	4	15

Topics that are only partly addressed and not explicitly directed to the SLCP are indicated by (x).

with other FFs. *Wood production* was expected to be low as tree growth will be slow as a result of high elevations and chronic water shortages. Instead, participants stated that alternative sources related to income from *non-wood products* (8·0), for example, fruit production, play a more important role. *Income from forest services and processing industry* (7·7) referring to maintenance activities and forest management were assessed to be of higher importance. The social FFs including the *provision of forest labour* (6·7) was considered to be of relatively low importance because of little working opportunities in the forest sector in general as the programme mainly aims to establish ecological forests (restricted use). *Health* (7·3), in this case related to clean (dust-free) air, was considered to be of high importance because frequently occurring dust storms harm the health of local people. *Access to forests* (7·0) was also perceived important for collecting fuel wood.

Land Use Functions and Forest Functions Addressed in the Literature

Analysis of the literature revealed differences in topics of available impact studies ($n = 40$). As shown in Table III, most studies have focused on economic and social impacts of the SLCP and were mainly related to agriculture (land-based production, $n = 26$; income, $n = 16$; and work, $n = 13$). With regard to forest management, fewer studies were available and were looking at economic wood production ($n = 8$) and forest industry and services ($n = 8$), whereas non-wood production (i.e. fruit production) were only partly addressed ($n = 6$). Only few studies were addressing social issues related to the *forest labour* sector ($n = 4$), health ($n = 4$) and the role of land rights ($n = 4$). Environmental studies have mainly addressed soil and water conservation issues ($n = 13$) and issues related to ecosystem processes ($n = 15$). Infrastructure ($n = 3$) and biodiversity ($n = 4$) were usually only mentioned but not part of the analysis.

Topics that were less often addressed in the literature although of relatively high importance to the regional group and to the forest group included biodiversity and non-wood production, respectively.

Assessment of the Economic Dimension

Land-based production and wood production (ECO1)

The regional group assessed the conversion of cropland into forest towards 2020 to increase the overall economic production from land in Guyuan (S2, S3) compared with the reference situation of continued crop production (S1) (Table IV). The forest group assessed the potential economic benefits from wood production to be positive under economic forests (F1), but to perform negatively under ecological forests (F2) and limited with energy forests (F3) (Table IV). The quite different perception in the regional group that afforestation would contribute to economic development

Table IV. Scenario impact assessment results on regional land use functions and forest functions (explanations of corresponding functions can be found in Table II)

Scenario	ECO 1		ECO 2		ECO 3		SOC 1		SOC 2		SOC 3		ENV 1		ENV 2		ENV 3		Aggregated impact			
	w	*i*	*w*	*i*	*w*	*i*	*w*	*i*	*w*	*i*	*w*	*i*	*w*	*i*	*w*	*i*	*w*	*i*	w_{ECO}	w_{SOC}	w_{ENV}	*wi*
S1 (REF/crop)	8·5	0·4	6·0	0·7	6·1	1·0	6·1	−0·4	7·0	−1·0	7·1	0·1	6·5	−0·8	7·6	−1·9	7·5	−1·0	13·7	−8·7	−27·1	−22·2
S2 (SLCP 1)		1·4		1·0		1·0		−0·4		1·7		1·4		1·4		1·8		1·7	24·0	19·4	35·5	78·9
S3 (SLCP 2)		1·7		1·4		1·6		−1·1		2·2		2·1		2·4		2·8		2·8	32·6	23·6	57·9	114·1
F1 (economic)	6·0	0·8	8·0	2·8	7·7	2·3	6·7	2·3	7·3	1·8	7·0	2·5	8·7	0·4	7·7	0·5	9·7	−0·4	16·9	17·3	1·4	94·4
F2 (ecological)		−0·9		0·3		0·1		−0·8		3·0		0·3		2·7		2·8		2·5	−0·6	7·2	18·7	85·7
F3 (energy)		0·8		1·4		1·5		0·1		1·4		1·6		0·7		1·5		1·1	10·3	7·7	7·3	78·0

Note: *wi*, weighted impact; *w*, weight assigned to each function; *i*, average impact for each function; *d*, sustainability dimension (economic, social, environmental); *f*, function ($n = 9$). Results of the forest scenario assessment (F1–3) are adapted from König (2010) with permission.

was based on the assumption that planting forests would generally maximize the economic use of marginal land.

Wood production does not play a considerable role in Guyuan as unfavourable environmental conditions (water scarcity, high elevations) limit commercial forestry in this region (Cao *et al*., 2009). Economic returns from energy forests (F3) were assessed to provide some benefits, but this type of forest management has not been established in Guyuan yet and might therefore only be realized at small scale. In this regard, Tang *et al*. (2010) mentioned the potential of growing shrubs for energy production on less productive sites.

Non-land-based production and non-wood production (ECO2)

The regional group expected the SLCP to stimulate non-land-based development (expansion of build-up areas) (S2, S3) (Table IV) based on the assumption that the SLCP will contribute to rural economic development through structural changes. However, this aspect might be difficult to be attributed directly to the programme because high economic development at national level has pushed construction activities in China (Zhen *et al*., 2010).

With regard to non-wood production, the two main limiting factors to plant economically attractive trees (mainly fruit trees) are water scarcity and lack of management skills. Although about 20 per cent of the afforested land in Guyuan is dedicated to economic forests (F1), a major concern mentioned by the workshop participants was that farmers might not have sufficient knowledge for actually managing forests and lack technical equipment for maintenance and harvesting. The issue of insufficiently skilled labour forces in the growing forest sector is also addressed by Weyerhaeuser *et al*. (2005). Several studies found that farmers would favour to convert land into economic forests (e.g., Weyerhaeuser *et al*., 2005; Yang, 2004; Ye *et al*., 2003), but the decision of tree selection (and provision) is usually taken by the local governments (Bennett *et al*., 2011).

Infrastructure and (forest) industry and services (ECO3)

Similar to the results of *non-land-based production* (ECO2) *infrastructure* (ECO3) development was assessed to benefit under the SLCP (S2, S3) (Table IV), assuming that the programme will lead to higher investments into road construction projects in Guyuan. However, there is no evidence to prove this result although some other SLCP studies addressed the negative impact of roads on soils (compaction, erosion) in general (Chen *et al*., 2009; Stokes *et al*., 2010) but without explicit link to the SLCP.

In the forest group, both, economic and energy forests (F1, F3) were assessed to develop (forest) industry and service sector, including the processing of fruits (packing, selling) and the provision and installation of energy systems (e.g., small energy plants, stoves). Besides some cultivated fruit trees (e.g., nuts, apricot, apple), cultivation and processing of wolfberry *(Lycium chinense)* is considered a major economic fruit-shrub in Guyuan a region which is well suited to it (Mi *et al*., 2011). Most afforestation sites are restricted to grow economically valuable fruit trees at larger scales and thus limit the establishment of the fruit processing industry. Since forest work is usually done by manpower, forest services will likely be required to manage and maintain forest land (e.g., planting, thinning, pruning, harvesting).

Assessment of the Social Dimension

Provision of work and forest labour (SOC1)

The most negative impact of the SLCP in Guyuan assessed by the regional and the forest groups, respectively, referred to a reduction of work (S2, S3, F2) (Table IV), worsened by the limited flexibility to leave the farm (lack of mobility and low education). During field interviews, local farmers reported that the older generation of farmers, in particular, had difficulties in adapting to such changes relying on governmental support more than younger generations (see also Uchida *et al*., 2009). The potential contribution of afforested land to provide rural work will be limited in the future because economic forests (F1) play a minor role in Guyuan. Chen *et al*. (2009) argues that releasing labour forces from agriculture could stimulate a shift towards off-farm work. However, a regional study of Uchida (2007) conducted in Ningxia (the province to which Guyuan belongs) found little evidence for participating farm households shifting labour to alternative off-farm activities due to mobility constraints and actually preferring to stay on the farm.

Quality of life (income) and health (SOC2)

Changes in rural income towards 2020 were assessed to increase under the implementation of the SLCP (S2, S3; Table IV) as a result of increasing income generated from fruits harvested from planted trees and contributing to shift agricultural activities towards the off-farm sector. The increasing importance of the off-farm sector for generating rural income has also been found by several other impact studies (e.g., Ediger and Chen, 2006; Liu *et al*., 2010; Yao *et al*., 2010). Following the major goal to combat soil erosion, all forest management scenarios (F1–3, Table IV) revealed that wind erosion and dust pollution will likely be reduced, an important health aspect for rural people in Guyuan. Several studies reported on the success of revegetating hillslopes reducing soil erosion (e.g., Chen and Cai, 2006; Stokes *et al*., 2010; Zheng, 2006); other authors questioned this aspect with particular reference to semi-arid regions of the Loess Plateau, referring to high tree mortality rates, and thus failure to establish permanent soil cover (Cao *et al*., 2007; Chen *et al*., 2007c).

Food security and access to forests (SOC3)

Food security has long been a concern in rural China, and particular attention was paid under the circumstances that cropland will be converted into forests and grassland. However, the regional group was optimistic by positively assessing the SLCP to contribute to an improved situation of food availability in Guyuan (Table IV), on the basis of the assumption that only marginal land will be taken out of production. Studies by Yang (2004) and Dai (2010), however, found that some of the farmers enrolled in the programme were able to increase production on the remaining land. Several other studies explicitly analyzed the programme's effects on food security (e.g., Feng *et al*., 2005; Peng *et al*., 2007; Xu *et al*., 2006; Zhen *et al*., 2009a). Feng *et al*. (2005) indicated that food security in Western China might be more important than in other regions in China as a result of supply constraints; and that, although food security might not be affected at national level, local impacts could be significant. However, a recent study by Zhen *et al*. (2009a) found that increasing meat consumption of people in Guyuan indicates changes in the diets of rural people that might lead to increasing demands on grain supply in the future.

The right to access forests to collect fuel wood was assessed positively by the forest group for all scenarios (F1–3). Comparable studies explicitly addressing this issue do not exist however; it is known that land *per se* does not belong to the farmer himself.

Assessment of the environmental dimension

Environmental functions were not differentiated in both groups.

Provision of abiotic resources (ENV1)

All SLCP scenarios (S2, S3, F1–3; Table IV) were assessed to improve the soil quality in Guyuan through afforestation by the regional group and the forest group. The common assumption was that revegetating eroded land with trees will reduce soil erosion. It is widely accepted that vegetation cover is a means to control soil erosion (Zheng, 2006). Cao *et al*. (2008), however, pointed at the risk that large-scale afforestation that might lead to higher soil erosion problems in the long run as a result of using fast growing tree species (e.g., Pine, Locust, Poplar), instead of using natural vegetation (e.g., native shrubs, Birch, Oak) leading to water stress and tree mortality, while Yang *et al*. (2010) stressed the challenge of the low resilience in semi-arid regions of the Loess Plateau and supported the need to plant trees and establish grassland for a timely recovery of degraded soils. The debate included aspects of whether native species should be considered.

Provision of biotic resources (ENV2)

Afforestation and forest management were both assessed to improve the quality of habitats and increase biodiversity of regional flora and fauna. Having in mind that Guyuan is dominated by agriculture, forests will contribute to higher landscape diversity. Although this seems generally plausible, Cao *et al*. (2009) pointed at the risk that the programme-induced introduction of non-native species might harm the existence of native species. An empirical study explicitly addressing the impact of the SLCP on habitat quality and biodiversity has not been conducted yet.

Maintenance of ecosystem processes (ENV3)

Apart from economic forests (F1), the SLCP scenarios (S2, S3) and forest management scenarios F2 and F3 (Table IV) were assessed to enhance key ecosystem processes in Guyuan. However, both groups might have overestimated the positive effect of ecological forests. Among the main tree species established in Guyuan, pine forests (*Pinus sp.*) were found to contribute to the highest water losses due to high surface runoff (assuming that ground vegetation is missing) followed by cropland, grassland and shrubland (Chen *et al*., 2007a). In the long run, tree mortality problems due to water stress might also occur for two other tree species used for afforestation purposes, including Locust (*Robinia sp.*) and Poplar (*Populus sp.*) (Fischer, 2010). In this regard, Sun *et al*. (2006) pointed at the potential reduction in water yields caused by planted trees in the semi-arid north of China where, naturally, grassland, shrubs and small trees grow (Cao *et al*., 2011). Instead, Cao (2011) put forward the need to orient at 'close-to-nature' species (native and regionally well adapted species), which could improve and sustain forest quality in the longer term.

Assessment of regional SLCP impacts: an integrated view

Aggregation of impacts (Table IV) allows for a weighted interpretation of SLCP scenario impacts at regional context. If first looking at the implementation scenarios of the SLCP in Guyuan (S2, S3), the main trade-offs occur between *provision of work* (SOC1) and the conservation of environmental functions (ENV1–3). Without the SLCP (S1), particularly the environmental (ENV1-3) and partly also the social dimension (SCO1 and 3) were assessed to face a continuing negative development in Guyuan, while the main positive impacts of the SLCP are clearly on the environmental dimension, which was also of high priority as reflected in the weights assigned to the LUFs (Table IV). The results suggest that an expansion of the SLCP (S3) would contribute most to sustainable development in Guyuan towards 2020.

Regarding the regional forest management, trade-offs vary among scenarios (F1–3) (Table IV). The economic forest scenario economic forest (F1), for example, has the highest positive impact on all economic functions (ECO1–3) and some social functions (SOC1 and 3) but a negative impact on the regional water balance (ENV3). The ecological forest scenario (F2) contributes to the highest benefit of all environmental functions (ENV1–3) but was assessed negatively for *wood production* (ECO1) and *provision of work* (SOC1). The energy forest scenario (F3) was assessed to have little, but overall positive impact on all nine FFs. The results suggest, firstly, considering the possibility of establishing energy forests (F3), which might be a promising alternative to contribute to farm income and environmental conservation at the same time (small scale). Secondly, an integration of ecological and economic forests (F1, F3) at large scale could potentially lower the mentioned trade-offs but would require adequate long-term forest management strategies, e.g., by promoting selective cutting of trees instead of clear cuts.

Reflection on the assessment approach

The participatory impact assessment approach used has the potential to reveal possible trade-offs between economic, social and environmental sustainability dimensions that might occur as a result of the SLCP. In reflection to other studies where the FoPIA was used (e.g., in Indonesia, König *et al*., 2010; in Tunisia, König *et al*., in press), we found that a flexible but well-structured framework to study causal relationships between policies, land use changes and sustainability while also integrating local knowledge and different disciplines. Participating experts (scientists) and stakeholders (regional decision makers) reported that the FoPIA is relatively easy to understand and appreciated that this approach provides quick results. However, the quality of the results largely depends on the scenarios developed, the indicators selected and the stakeholders considered. For example, during the expert-based impact assessment, the regional group appeared to be very optimistic about possible SLCP impacts, whereas the forest group was more critical about programme effects. Although the regional group might have been biased of being in favour of the SLCP, their participation and knowledge contributed to an enhanced understanding of the regional problem issues and the implementation of the SLCP in Guyuan.

CONCLUSIONS

A clear win–win scenario leading to positive developments for all LUFs or FFs, respectively, could not be identified. Both workshop groups assessments (the regional group and the forest group) expected the SLCP programme to achieve the major goal of environmental rehabilitation but at the cost of reducing rural working opportunities because ecological forests alone provide only few employment and income opportunities beyond the project’s lifetime. Overall, with the assigned priorities to the FFs and LUFs, a continuation of the SLCP afforestation appeared to be most beneficial of all scenarios for rural sustainability in Guyuan. The economic forest scenario was assessed to serve primarily the economic and social sustainability dimensions, while environmental impacts were also tolerable. Energy forest is potentially benefiting all three sustainability dimensions (economic, social, environmental) but might only be realized at small scale because this type of forest management is not well established in Guyuan yet. A scenario with a sole focus on ecological forests had disproportionate positive impacts on environmental functions and little or adverse impact on the other two sustainability dimensions. Considering that Guyuan is a drought-prone region, long-term failures of afforestation might occur as a result of water stress and the use of water demanding tree species. Forest managers, therefore, might reconsider the choice of planting more shrubs or native tree species for the second implementation phase of the SLCP. Finally, we conclude that the here proposed assessment approach using both qualitative knowledge and quantitative information, could enhance the understanding of regional causal linkages between the SLCP land conversion programme and possible impacts on economic, social and environmental sustainability dimensions.

ACKNOWLEDGEMENTS

This study could be realized with financial and logistical support of the Chinese-German Centre for Impact Assessment (www.cgcia.org), Robert Bosch Foundation and the National Key Project for Basic Research of China (No. 2009CB421106). The authors wish to thank the numerous workshop participants for taking the time to participate in the FoPIA workshops and sharing their experiences and knowledge with us. We also thank Yunjie Wei, Li Fen, Long Xin, Lou Wei and Dirk Pohle for their support during the FoPIA workshops.

REFERENCES

Bennett MT. 2008. China’s sloping land conversion program: Institutional innovation or business as usual? *Ecological Economics* **65**: 699–711.

Bennett MT, Mehta A, Xu J. 2011. Incomplete property rights, exposure to markets and the provision of environmental services in China. *China Economic Review* **22**: 485–498.

Cao S. 2008. Why large-scale afforestation efforts in China have failed to solve the desertification problem. *Environmental Science & Technology* **42**: 1826–1831.

Cao S. 2011. Impact of China’s large-scale ecological restoration program on the environment and society in arid and semiarid areas of China: Achievements, problems, synthesis, and applications. *Critical Reviews in Environmental Science & Technology* **41**: 317–335.

Cao S, Chen L, Xu C, Liu Z. 2007. Impact of three soil types on afforestation in China’s Loess Plateau: Growth and survival of six tree species and their effects on soil properties. *Landscape & Urban Planning* **83**: 208–217.

Cao S, Chen L, Yu X. 2009. Impact of China's Grain for Green Project on the landscape of vulnerable arid and semi-arid agricultural regions: a case study in northern Shaanxi Province. *Journal of Applied Ecology* **46**: 536–543.

Cao S, Sun G, Zhang Z, Chen L, Feng Q, Fu B, McNulty S, Shankman D, Tang J, Wang Y, Wei X. 2011. Greening China naturally. *Ambio* **40**: 828–831.

Chen H, Cai Q. 2006. Impact of hillslope vegetation restoration on gully erosion induced sediment yield. *Science in China, Series D: Earth Sciences* **49**: 176–192.

Chen L, Gong J, Fu B, Huang Z, Huang Y, Gui L. 2007b. Effect of land use conversion on soil organic carbon sequestration in the loess hilly area, Loess Plateau of China. *Ecological Research* **22**: 641–648.

Chen LD, Huang ZL, Gong J, Fu BJ, Huang YL. 2007a. The effect of land cover/vegetation on soil water dynamic in the hilly area of the Loess Plateau, China. *Catena* **70**: 200–208.

Chen X, Lupi F, He G, Ouyang Z, Liu J. 2009. Factors affecting land reconversion plans following a payment for ecosystem service program. *Biological Conservation* **142**: 1740–1747.

Chen LD, Wang J, Fu BJ, Qiu Y. 2001. Land-use change in a small catchment of northern Loess Plateau, China. *Agriculture, Ecosystems & Environment* **86**: 163–172.

Chen L, Wei W, Fu B, Lu Y. 2007c. Soil and water conservation on the Loess Plateau in China: review and perspective. *Progress in Physical Geography* **31**: 389–403.

Ediger L, Chen H. 2006. Upland China in transition—The impacts of afforestation on landscape patterns and livelihoods. *Mountain Research & Development* **26**: 220–226.

Feng ZM, Yang YZ, Zhang YQ, Zhang PT, Li YQ. 2005. Grain-for-green policy and its impacts on grain supply in West China. *Land Use Policy* **22**: 301–312.

Fischer A. 2010. Forest restoration in the Loess Plateau in central China: Principles from the perspective of vegetation ecology. *Forst und Holz* **65**: 23–27.

Gates JB, Scanlon BR, Mu XM, Zhang L. 2011. Impacts of soil conservation on groundwater recharge in the semi-arid Loess Plateau, China. *Hydrogeology Journal* **19**: 865–875.

Grosjean P, Kontoleon A. 2009. How sustainable are sustainable development programs? The case of the sloping land conversion program in China. *World Development* **37**: 268–285.

Helming K, Diehl K, Bach H, Dilly O, Konig B, Kuhlman T, Perez-Soba M, Sieber S, Tabbush P, Tscherning K, Wascher D, Wiggering H. 2011. Ex ante impact assessment of policies affecting land use, Part A: Analytical Framework. *Ecology & Society* **16**: 27.

Huang T, Pang Z. 2011. Estimating groundwater recharge following land-use change using chloride mass balance of soil profiles: A case study at Guyuan and Xifeng in the Loess Plateau of China. *Hydrogeology Journal* **19**: 177–186.

König HJ. 2010. Multifunctional forest management in Guyuan: Potentials, challenges and trade-offs. *Journal of Resources & Ecology* **1**: 300–310.

König HJ, Schuler J, Suarma U, McNeill D, Imbernon J, Damayanti F, Dalimunthe SA, Uthes S, Sartohadi J, Helming K, Morris J. 2010. Assessing the impact of land use policy on urban–rural sustainability using the FoPIA approach in Yogyakarta, Indonesia. *Sustainability* **2**: 1991–2009.

König HJ, Sghaier M, Schuler J, Abdeladhim M, Helming K, Tonneau J-P, Ounalli N, Imbernon J, Morris J, Wiggering H. in press. Participatory Impact Assessment of Soil and Water Conservation Scenarios in Oum Zessar Watershed, Tunisia. Environmental Management.

Liu C, Lu JZ, Yin RS. 2010. An estimation of the effects of China's priority forestry programs on farmers' income. *Environmental Management* **45**: 526–540.

Mi W, Liu K, Zhao Y, Zheng C, Shi Z, Hao J, LuKun. 2011. Initial selection of plant species for ecological restoration in salinized soil in Datong Basin. *Journal of Beijing Forestry University* **33**: 49–54.

Morris J, Tassone V, De Groot R, Camilleri M, Moncada S. 2011. A Framework for Participatory Impact Assessment' (FoPIA): Involving stakeholders in European policy-making, a case study of land use change in Malta. *Ecology & Society* **16**: 12.

Peng H, Cheng G, Xu Z, Yin Y, Xu W. 2007. Social, economic, and ecological impacts of the "Grain for Green" project in China: A preliminary case in Zhangye, Northwest China. *Journal of Environmental Management* **85**: 774–784.

Pérez-Soba M, Petit S, Jones L, Bertrand N, Briquel V, Omodei-Zorini L, Contini C, Helming K, Farrington JH, Mossello MT, Wascher D, Kienast F, Groot R. 2008. Land use functions—A multifunctionality approach to assess the impact of land use changes on land use sustainability. In *Sustainability impact assessment of land use changes*, Helming K, Pérez-Soba M, Tabbush P (eds). Springer: Berlin-Heidelberg; 375–404.

Reed MS, Dougill AJ, Taylor MJ. 2007. Integrating local and scientific knowledge for adaptation to land degradation: Kalahari rangeland management options. *Land Degradation & Development* **18**: 249–268.

Reidsma P, König H, Feng S, Bezlepkina I, Nesheim I, Bonin M, Sghaier M, Purushothaman S, Sieber S, van Ittersum MK, Brouwer F. 2011. Methods and tools for integrated assessment of land use policies on sustainable development in developing countries. *Land Use Policy* **28**: 604–617.

Schwilch G, Bestelmeyer B, Bunning S, Critchley W, Herrick J, Kellner K, Liniger HP, Nachtergaele F, Ritsema CJ, Schuster B, Tabo R, van Lynden G, Winslow M. 2011. Experiences in monitoring and assessment of sustainable land management. *Land Degradation & Development* **22**: 214–225.

Sieber S, Müller K, Verweij P, Haraldsson H, Fricke K, Pacini C, Tscherning K, Helming K, Jansson T. 2008. Transfer into decision support: The Sustainability Impact Assessment Tool (SIAT). In *Sustainability impact assessment of land use changes*, Helming K, Perez-Soba M, Tabbusch P (eds). Springer: Berlin-Heidelberg; 107–128.

Stokes A, Sotir R, Chen W, Chestem M. 2010. Soil bio- and eco-engineering in China: Past experience and future priorities Preface. *Ecological Engineering* **36**: 247–257.

Stringer LC, Reed MS. 2007. Land degradation assessment in southern Africa: Integrating local and scientific knowledge bases. *Land Degradation & Development* **18**: 99–116.

Sun G, Zhou GY, Zhang ZQ, Wei XH, McNulty SG, Vose JM. 2006. Potential water yield reduction due to forestation across China. *Journal of Hydrology* **328**: 548–558.

Tang Y, Xie JS, Geng S. 2010. Marginal land-based biomass energy production in China. *Journal of Integrative Plant Biology* **52**: 112–121.

Uchida E, Rozelle S, Xu J. 2009. Conservation payments, liquidity constraints, and off-farm labor: impact of the grain-for-green program on rural households in China. *American Journal of Agricultural Economics* **91**: 70–86.

Uchida E, Xu JT, Rozelle S. 2005. Grain for green: Cost-effectiveness and sustainability of China's conservation set-aside program. *Land Economics* **81**: 247–264.

Uchida E, Xu JT, Xu ZG, Rozelle S. 2007. Are the poor benefiting from China's land conservation program? *Environment & Development Economics* **12**: 593–620.

Uthes S, Fricke K, König H, Zander P, van Ittersum M, Sieber S, Helming K, Piorr A, Müller K. 2010. Policy relevance of three integrated assessment tools - A comparison with specific reference to agricultural policies. *Ecological Modelling* **221**: 2136–2152.

Vogt JV, Safriel U, Von Maltitz G, Sokona Y, Zougmore R, Bastin G, Hill J. 2011. Monitoring and assessment of land degradation and desertification: Towards new conceptual and integrated approaches. *Land Degradation & Development* **22**: 150–165.

Weyerhaeuser H, Wilkes A, Kahrl F. 2005. Local impacts and responses to regional forest conservation and rehabilitation programs in China's northwest Yunnan province. *Agricultural Systems* **85**: 234–253.

Xu ZG, Bennett MT, Tao R, Xu JT. 2004. China's sloping land conversion programme four years on: Current situation and pending issues. *International Forestry Review* **6**: 317–326.

Xu ZG, Xu JT, Deng XZ, Huang JK, Uchida E, Rozelle S. 2006. Grain for green versus grain: Conflict between food security and conservation set-aside in China. *World Development* **34**: 130–148.

Yang H. 2004. Land conservation campaign in China: Integrated management, local participation and food supply option. *Geoforum* **35**: 507–518.

Yang X, Jia Z, Ci L. 2010. Assessing effects of afforestation projects in China. *Nature* **466**: 315.

Yao SB, Guo YJ, Huo XX. 2010. An empirical analysis of the effects of China's land conversion program on farmers' income growth and labor transfer. *Environmental Management* **45**: 502–512.

Ye YQ, Chen GJ, Hong F. 2003. Impacts of the "Grain for Green" project on rural communities in the Upper Min River Basin, Sichuan, China. *Mountain Research & Development* **23**: 345–352.

Yin RS, Yin GP. 2010. China's primary programs of terrestrial ecosystem restoration: Initiation, implementation, and challenges. *Environmental Management* **45**: 429–441.

Zhang K, Dang H, Tan S, Cheng X, Zhang Q. 2010. Change in soil organic carbon following the 'grain-for-green' programme in China. *Land Degradation & Development* **21**: 13–23.

Zhen L, Cao S, Cheng S, Xie G, Wei Y, Liu X, Li F. 2009a. Arable land requirements based on food consumption patterns: Case study in rural Guyuan District, Western China. *Ecological Economics* **69**: 1443–1453.

Zhen L, Cao S, Wei Y, Dilly O, Liu X, Li F, Koenig H, Tscherning K, Helming K. 2009b. Comparison of sustainability issues in two sensitive areas of China. *Environmental Science & Policy* **12**: 1153–1167.

Zhen L, Wei Y, Xie G, Helming K, Cao S, Yang L, Pan Y, König H. 2010. Regional analysis of dynamic land use functions in china. *Shengtai Xuebao/Acta Ecologica Sinica* **30**: 6749–6761.

Zheng F-L. 2006. Effect of vegetation changes on soil erosion on the Loess Plateau. *Pedosphere* **16**: 420–427.

Zhu FS, Rochin RI, Chiao YS. 1986. Farming and optimal resource utilization in Guyuan, China. *Food Policy* **11**: 133–142.

