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An integrated assessment model of carbon sequestration benefits: A case study of Liping county, China

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Abstract

This research attempts to model the complexity of planting trees to increase China's CO_2 sequestration potential by using a GIS-based integrated assessment (IA) approach. We use the IA model to assess the impact of China's Grain for Green reforestation and afforestation program on farmer and state incomes as well as CO_2 sequestration in Liping County, Guizhou Province. The IA model consists of five sub-models for carbon sequestration, crop income, timber income, Grain for Green, and carbon credits. It also includes a complementary qualitative module for assessing program impacts by gender and ethnicity. Using four scenarios with various assumptions about types of trees planted, crop incomes by township, CO_2 credit prices, state subsidies, methods for estimating carbon sequestered, and harvesting of trees, we find great variation in the impact of the Grain for Green program on incomes and on carbon sequestered over a 48 year period at both the county and township levels.

Keywords: Integrated assessment; China; Carbon sequestration; GIS-based modelling; Grain for Green; Reforestation; Household Survey

1. Introduction

As China continues its rapid rate of development, dealing with the massive and growing emissions of CO_2 in the country will be vital in the context of global climate change. One option for reducing the amount of CO_2 in the atmosphere is to absorb and store the CO_2 in vegetation biomass and soil by planting trees. China currently has one of the world's most ambitious reforestation and afforestation programs, known as Grain for Green. This program has been in place since 1999, with the goal of reducing soil erosion by converting steep-sloping agricultural and barren land to forestland. Although not one of its goals, carbon sequestration is a co-benefit of the program.

Grain for Green gives grain payouts to farmers who convert fields to forests. It is operating in many different regions in China, including Guizhou Province. Guizhou (see Fig. 1) is one of the poorest provinces in China and Liping County, the site of this research, is one of the poorest counties in the province. In 2003, Liping's per capita GDP was only 43.5% of the provincial average and 16.7% of the national average (Liping Statistics Bureau, 2003; National Bureau of Statistics, 2004). Located in the southeast corner of Guizhou Province, far from the major urban centers of Guiyang and Zunyi, the county's population of 503,000 is predominantly rural (92%) and relies heavily on agriculture and forestry as sources of income.

To date, assessments of the Grain for Green program have focused on the benefits of soil conservation and the program's impacts on farmer income, while ignoring potential carbon sequestration benefits (cf. Ye et al., 2003; Xu et al., 2004; Uchida et al., 2005). Calculating the carbon sequestration benefits of the program could provide additional justification for its continuation, not just because of the environmental benefits of carbon sequestration but also because of the potential economic

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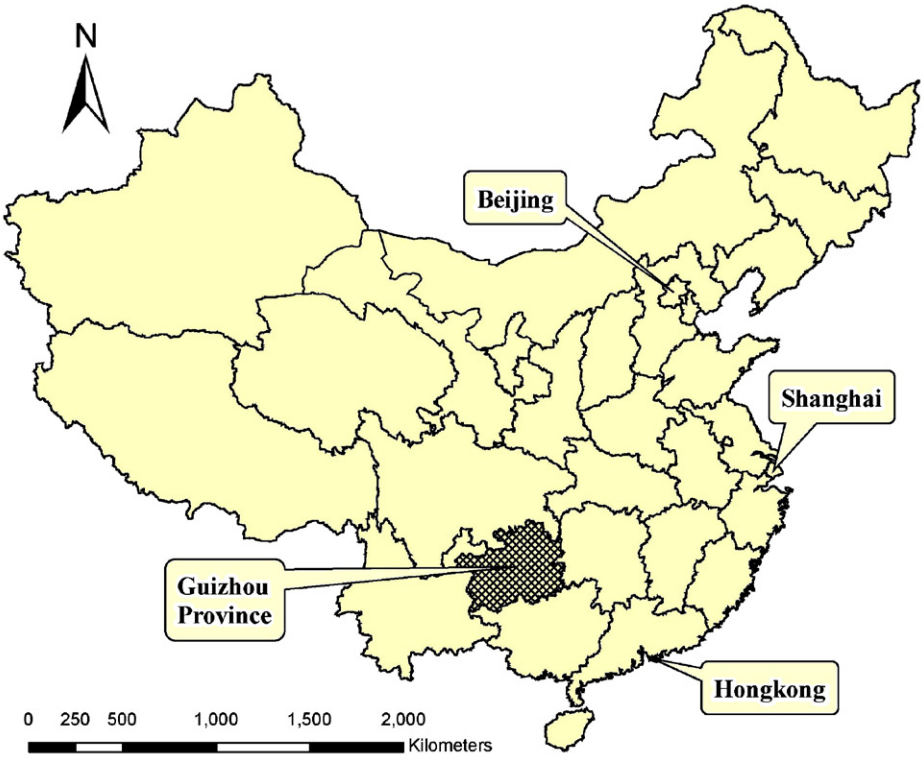

Fig. 1. China, showing Guizhou Province.

benefits from selling carbon credits on the world market. Although there is still considerable uncertainty about the potential economic returns from selling carbon credits under the Clean Development Mechanism, due to unresolved methodological issues (Smith et al., 2000; Van Vliet et al., 2003), these credits could provide substantial income to the state and possibly help to subsidize reforestation and afforestation efforts.

This paper presents a spatially disaggregated integrated assessment (IA) model that allows for the simultaneous quantitative assessment of carbon sequestration and farmer and state income streams arising from conversion of cropland and barren land to forests. We also include a complementary qualitative assessment of the relative impacts of the program by gender and ethnicity. IA models of the type used here assess the combined output from different types of models, typically including physical and socio-economic models, with the objective of identifying a preferred scenario or policy action. The IA modelling approach was initially developed to be used with global climate change modelling (Jakeman and Letcher, 2003, p. 492; Toth et al., 2003), but IA has also been applied to regional scale issues such as catchment basin management (Jakeman and Letcher, 2003), climate change in the Pacific Northwest (Miles, 1995) and agrarian system modelling (Bland, 1999).

The sites chosen for assessment by the IA model are those that were converted as part of the Grain for Green program in Liping County in 2003. The model is meant to be used as a tool not only for assessment of the long-term impacts of existing reforestation and afforestation sites under the Grain for Green program, but also for assessment and choice of future sites. For the purposes of this paper, reforestation refers to planting trees on land that used to be forested but had been cut-down and used to grow crops within the last five decades. Afforestation occurs when trees are planted on land that was not forested in recent times, such as grass, scrub, or barren land.

2. Grain for green program

A newspaper article that frames the suicide of a rural farmer as a result of national policies shows the complexity of any policy implementation in China (Epstein, 2003). In the case of this farmer's suicide, the Grain for Green subsidies available to the farmer amounted to the provision of less grain than what had been produced on the reforested land before conversion, burdening the farmer with a debt that he could not repay. The article highlights how a well-intentioned program that may be in the interest of some farmers because they receive a greater value in subsidies than their land produces can have tragic consequences for other farmers. Hence, it is important to examine, as we do here, not only the overall impacts of a program such as Grain for Green, but also its disaggregated impacts (e.g. by income, location, gender and ethnicity).

The Grain for Green program in China began with pilot projects in three provinces in 1999 and later expanded to 25 provinces. It aims to convert cultivated and degraded land

Table 1
Townships of Liping, % land with slope of 25° or more

Name of township	Land in township with slope of 25° or more		Average slope of 2003 reforested area in township (degrees)	Area of land reforested (ha)
	(Hectares)	(Percentage)		
Áoshì	0.12	0.1	4.2	1.6
Bàzhài	1.17	0.9	7.6	25.1
Dàjià	10.40	8.7	13.6	102.9
Défèngzhēn	0.53	0.2	5.9	85.1
Déhuà	24.20	18.6	(No	
reforestation)	0.0			
Déshùn	1.47	0.6	3.3	76.1
Dìpíngxiàng	4.36	3.7	(No	
reforestation)	0.0			
Gāotúnzhēn	1.31	0.4	3.1	205.7
Hóngzhōu	6.16	2.0	7.4	23.5
Jiǔcháo	6.41	2.0	8.3	264.1
Kǒujiāng	6.72	5.2	13.0	42.9
Léidòng	5.60	6.8	6.7	4.9
Lóng'é	7.69	4.8	14.2	40.5
Lúolǐ	3.32	2.0	4.8	70.5
Máogòng	2.44	1.5	7.9	46.2
Mèngyàn	9.46	5.4	14.1	33.2
Píngzhài	14.26	15.7	16.0	69.7
Shàngzhòng	27.60	11.7	11.0	59.1
Shuāngjiāng	23.18	7.4	12.4	48.6
Shǔikǒu	7.02	2.8	10.8	46.2
Shùnhuà	0.63	1.1	7.6	64.8
Yándòng	2.66	1.8	7.5	59.9
Yǒngcóng	2.06	1.3	8.8	109.4
Zhàoxìng	8.91	5.6	7.5	21.1
Zhōngcháozhēn	0.89	0.3	5.3	26.7

on steep slopes to forests. About one-third of the conversions are to take place on very steep slopes greater than 25° (Xu et al., 2004) and a certain percentage of all cropland conversions must be matched by afforestation on publicly owned degraded land (Zuo, 2002). The farmers affected receive a subsidy of grain and money, amounts of which vary among different areas of China (Ye et al., 2003). Reforestation under the Grain for Green program began in Liping County in 2000 and afforestation began in 2003. Farmers there receive 2250 kg grain/ha of reforested or afforested land, together with 750 RMB/ha[1] for reforestation or afforestation costs and upkeep per year. These subsidies are given over a period of 8 years, with no current plan to extend the subsidy past the 8-year mark.

For Liping County, the requirement for one-third of converted land to have a slope greater than 25° imposed severe limits on where the reforestation and afforestation could occur. Overall, only 3.8% of the area of Liping has a slope that is 25° or more, with the township of Déhuà (which had no reforested areas in 2003) having the highest percentage of steep land at 18.6%, while Áoshì has the lowest at 0.1% (Table 1). In fact, in 2003, only 2.3% of the Grain for Green reforestation efforts in Liping occurred on land with a slope of 25° or more. Among the 23 townships that experienced reforestation, the average slope of the land reforested was 8.4°, with a range of 3.1° (in Gāotúnzhēn township) to 16° (in Píngzhài township). No data are available for the slopes of sites afforested in Liping in 2003.

3. Model conceptualization

The IA conceptual model (shown in Fig. 2) consists of five main elements: a carbon model, a crop income model, a timber income model, a carbon credit model and a Grain for Green Model. All five models feed into a scenario creation component out of which they produce township and county-level results. An assessment of gender and ethnicity impacts is also available as a complementary aspect of the other results. The following methodology section provides details about the functioning of the five models and the basis for the gender/ethnicity assessment.

4. Methodology

The spatially referenced bio-physical data used in this study came from a wide variety of sources. The socio-economic data came from a household survey conducted in all but six of Liping's 25 townships in 2004. The next two sections describe these data sets and their collection in detail. This is followed by a comprehensive description of model development and scenario construction.

4.1. Bio-physical data sources and format

The IA model used both remotely sensed (RS) data and ground-collected data. Employing a geographic information system (GIS) to incorporate the RS and ground-collected data into the IA model ensured that the spatial component of the project was kept intact and provided the additional benefit of improved visualization of the data.

The data for this research project came from a wide variety of sources. Partner Chinese universities and researchers provided the following data: digital elevation model (DEM), soil map, species map, township map, and satellite imagery. The DEM had a spatial resolution of 87.9 m, and was resampled to 90 m. The soil map had a resolution of roughly 1 km, and for Liping County had ten different soil types. The species map was heads-up digitized from a hardcopy scan. The original species map was from 1999, and had a scale of 1:10,000.

The species map covers 13 different types, with the relevant species being deciduous, Masson Pine, Chinese Fir, and bamboo. The township map is simply a vector map of the townships, at roughly a 1:10,000 scale. Lastly, the satellite data are Landsat ETM+ obtained on May 14 and May 21, 2000, with a 30 m resolution, using bands 1, 2, 3, 4, 5, and 7. These images were processed using the Boreal Ecosystem Productivity Simulator (BEPS) model, which

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[1] 8.01 RMB (rénmínbì) = US$ 1.00.

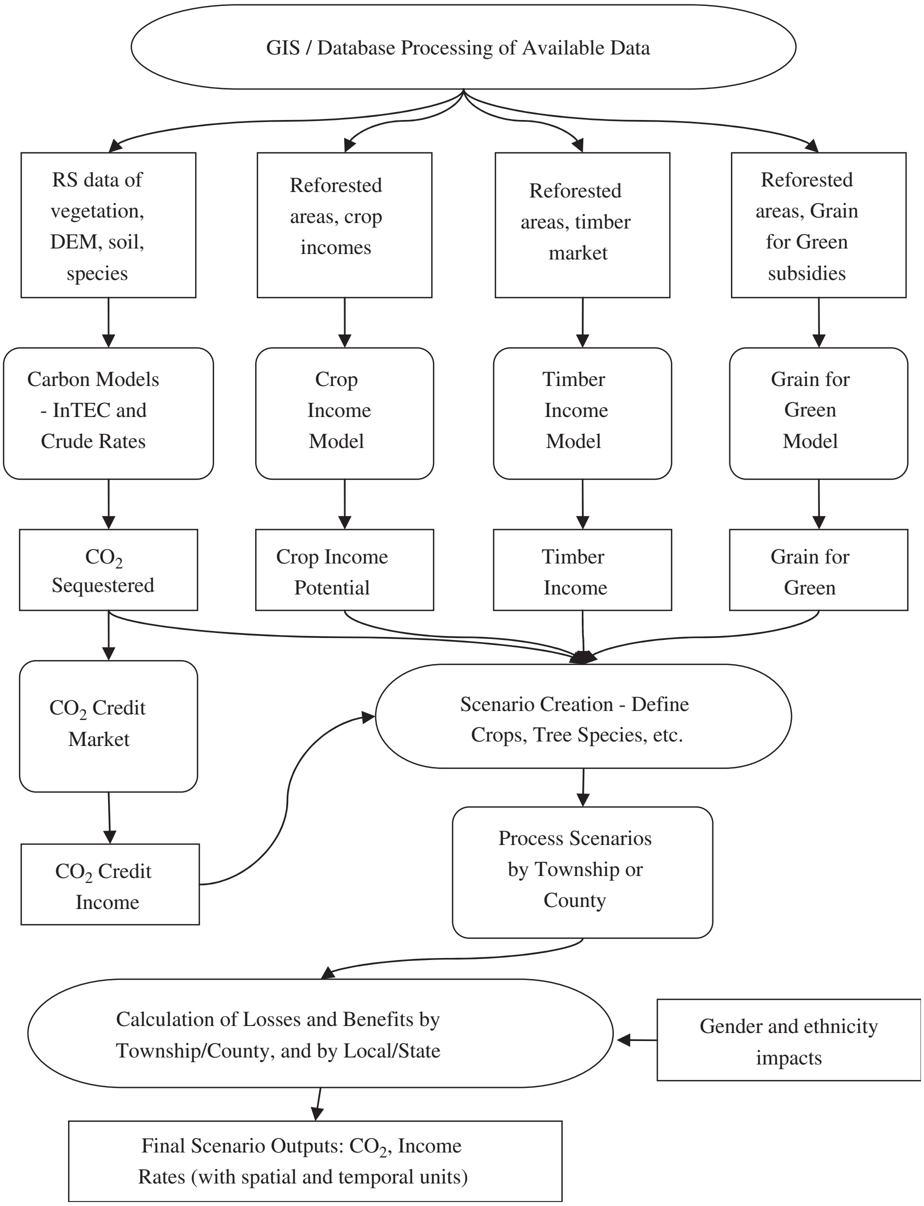

Fig. 2. The integrated assessment conceptual model.

had also been adjusted to local conditions (see Liu et al., 2002), to create a net primary productivity (NPP) map (Fig. 3), which quantifies the net gain of carbon in biomass each year. The partner institutions also provided background information and statistics on the Grain for Green program, timber markets, species growth rates, and net ecosystem productivity (NEP) rates. NEP is NPP less carbon release from soil due to dead organic matter decomposition. The Liping County forestry officials supplied detailed maps of Liping County including reforested and afforested plots. The afforestation program only began in Liping in 2003 and does not fall under the original Grain for Green program, but has been included where appropriate in this research to show potential additional CO_2 amounts into the future.

One significant gap was the lack of data on soil, specifically the current amount of CO_2 and the potential for further CO_2 sequestration. Soil plays an important role in the ecosystem in terms of carbon sequestration, since soil can hold up to 50% or more of the carbon in an ecosystem (Chapin et al., 2002). There were limited opportunities to collect additional data on the soil conditions in situ. The IA model represents soil using a low-resolution soil type map as one input into the Integrated Terrestrial Carbon Cycle Model (InTEC) model. However, the amount of CO_2 stored in soil used for agriculture is low.

The main variables include CO_2 sequestration amounts and net income. These variables were adjusted or standardized as necessary, such as income per farmer per hectare. Each variable has a spatial component, though the

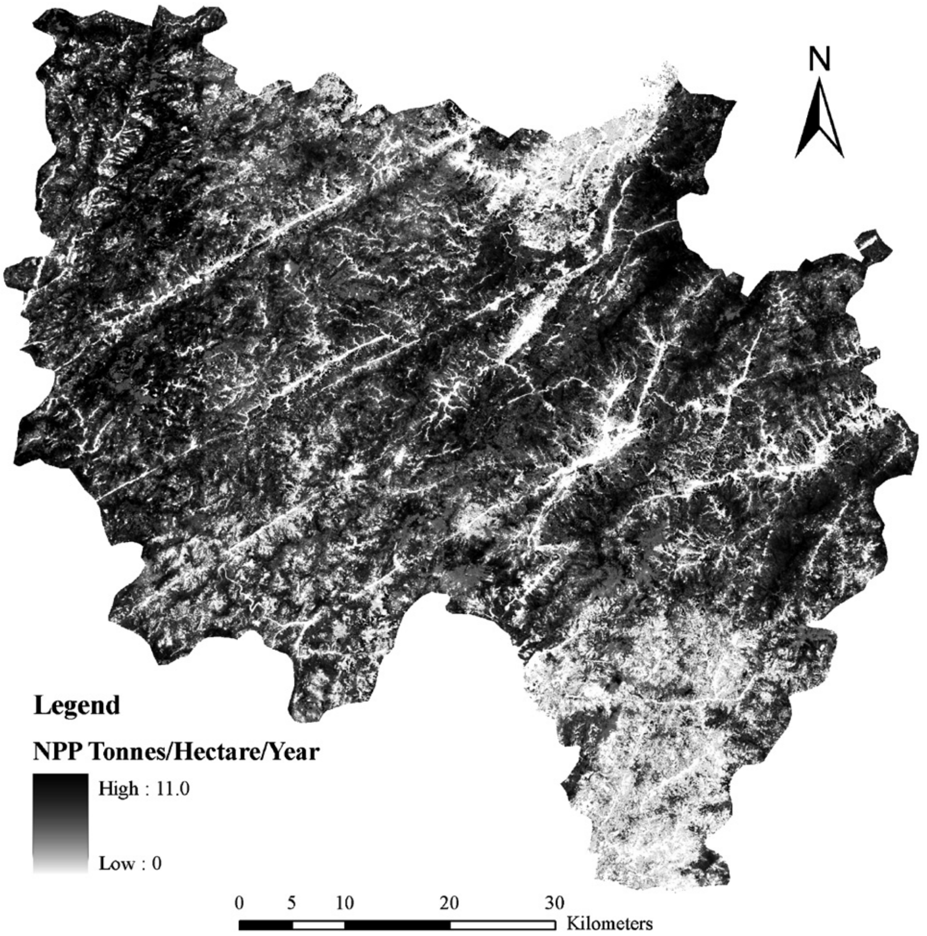

Fig. 3. Net primary productivity (NPP) map of Liping, as generated by the BEPS model.

scale was different depending on the variable. The common unit of analysis was the township level.

4.2. *Household survey design and administration*

The household survey was administered in July 2004, to 272 households in 19 of the 25 townships in Liping. The survey collected a range of data including: basic population data on ethnicity, education, and income; opinions about the Grain for Green program; land use, forest, and forest conversion financial details; and a series of questions on policy impacts, including gender-specific questions about changes in workload after the implementation of Grain for Green.[2] Selection of the survey participants was primarily the responsibility of the local forestry officials, and the majority of the surveys were conducted in-group sessions in local meeting halls or forestry offices.

The member of the household who filled out the survey also completed questions for other members in the household. The households selected for the survey were participants in the Grain for Green program and were meant to be representative of other Grain for Green participants in the county. The overwhelming majority of those who filled in the survey were male (92%). Those participating in the survey each received a cash payment of 10 RMB, or about US $1.25.

Each session of surveys took about 2–3 h. The ability of farmers to complete the surveys varied greatly. Some farmers were able to complete the entire survey on their own in about 1 h, while others required a great deal of assistance to complete it in 2–3 h. The eventual method of survey administration was to put the survey respondents into groups with at least one skilled respondent per group. The outside researchers experienced difficulties explaining how to complete the survey due to both linguistic and educational barriers. The help of the local forestry officials, who spoke the local dialect, as well as the more educated farmers, was essential to the successful completion of the surveys.

4.3. *The carbon model*

Two methods were used to calculate the amount of CO_2 sequestered in forests, a crude method and a comprehensive method based on an ecosystem model named the

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[2] The questionnaire did not distinguish between workload changes due to afforestation and changes due to reforestation.

InTEC (Chen et al., 2003). These methods produce outputs of NPP and NEP, respectively. NPP is the amount of carbon produced through tree biomass growth in the stems, leaves and roots, while NEP is the same as NPP less carbon release from soil due to heterotrophic respiration (organic matter decomposition). In a mature forest site, NEP would be close to zero as the gain of carbon in biomass from NPP is more or less balanced by the loss of carbon from soil through heterotrophic respiration. At reforested sites where crops were previously grown, the total biomass accumulation in trees may be a close approximation of the total carbon gain in the ecosystem as the slow carbon loss from the original agricultural soil is generally more than balanced by the transfer of new carbon to soil from tree litter and root turnover. The biomass accumulation is smaller than the accumulated NPP because of these transfers of carbon to soil. NPP and NEP are influenced by a variety of factors including climate, soil, elevation, precipitation, and nutrients. These effects are assumed to be already considered in the two CO_2 calculation methods, although such issues as climate change could be included within the InTEC model to provide additional variation in the estimates of long-term CO_2 sequestration.

4.3.1. The InTEC model

InTEC (Chen et al., 2003) was adjusted to closely match the ecosystem in Liping, China, including location-specific soil respiration coefficients (Shao et al., 2007). Data inputs for the InTEC model include a species map, elevation map, and NPP map generated from satellite imagery using the Boreal Ecosystem Productivity Simulator (BEPS) model, which had also been adjusted to local conditions (see Liu et al., 2002). Due to a lack of available tree species growth data, the outputs for the InTEC model are restricted to either deciduous or coniferous tree types. One important aspect of the model is that the area unit is independent, which means that there are no interactions among different areas. Instead of having to predefine certain areas as having a specific species group or mix of species groups, the InTEC model was run for each single species group covering the entire Liping County area. Either species group can be used in the model by matching the output to these reforested areas.

To generate the outputs from the InTEC model, the first step was to decide on model parameters. Given that each model simulation takes at least a few hours of processing time, the first decision was to create an output for the entire area of Liping for the two species groups—coniferous and deciduous. This would allow the selective use of different species groups for different sites based on either of the two model simulations. The model runs for the period 1901–2100, with historical climate data used for past years and simulated climate data used for future years. The historical and simulated climate data are part of the InTEC model. For the period 1901–2000, a landcover of basic crops was simulated covering all of Liping County, so that the amount of soil carbon at reforestation sites could be represented correctly without influence from other tree types. Soil carbon refers to organic C that is stored in the soil as dead roots and leaf detritus. The reforestation event was simulated in 2000, and represented the removal of crops and the planting of trees. This year was selected since it matches the satellite imagery for the creation of the NPP map; it is also the first year of the reforestation program in Liping. Therefore, the model year output for 2001 shows the first year of CO_2 sequestration as NEP. Given that the reforestation plots are from the years 2000–2003, the model could have been run additional times, simulating the reforestation event in each respective year. However, the difference in CO_2 sequestration rates for a tree species that is planted during any of these 4 years is near negligible, and given the magnitude of other sources of error (including the fact that the climate for the years beyond 2001 is simulated), it was much easier to simply model a single year and assume the same rates apply for the other start dates. Given reforestation start dates of 2000, 2001, 2002, and 2003, we assume that the respective output data for CO_2 sequestration rates in the first year of reforestation for each starting year are identical to the 2001 output data.

The final model outputs were a series of raster data images for Liping County, covering each year from 2001 to 2100, showing a cumulative value of CO_2 from NEP in kg/m^2, with a resolution of 90 m (see Figs. 4 and 5).

Final processing for CO_2 amounts were calculated using a raster calculator. The InTEC output was in kg/m^2. First, the areas of reforestation and afforestation were selected from the InTEC outputs and saved to a new data file. Then, this data file was processed to change the values into a total amount for each 90 m pixel, instead of a rate per pixel, by multiplying by the total area of a pixel, $8100\,m^2$. Finally, the Liping township map was overlaid on the CO_2 raster data, and the value of all the pixels within each township polygon were totalled, to give a final amount of kg of CO_2 per township.

4.3.2. The crude method

The second method used was a crude method based on existing empirical research. This method produces a range of CO_2 sequestration rates for different natural forests in China (see Table 2). These rates were provided by Nanjing Forestry University researchers, and are a compilation of their own site-specific results and from Chinese publications. The rates given include a high and low value, as well as an average value. Since Liping is a subtropical area, the values available for use are for deciduous and coniferous (warm and temperate climates) forests and bamboo. The values given are in tonnes of CO_2 accumulated per hectare per year. Using the area of land reforested and afforested on a township-by-township basis, total CO_2 sequestration was calculated for a single year and multiplied by the necessary number of years to give a total amount over time.

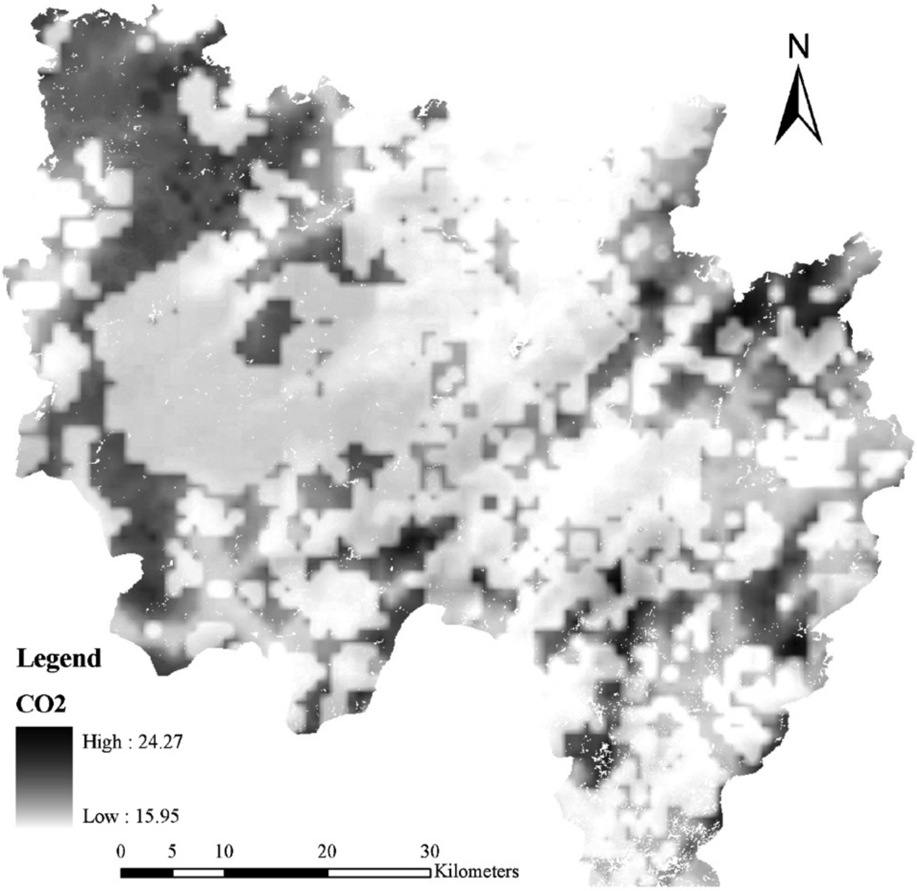

Fig. 4. Cumulative CO_2 for coniferous trees from the InTEC model in kg/m^2, with a resolution of 90 m, for the years 2003–2050.

The choice of the crude method was for two reasons. Firstly, the use of the crude method allows a comparison to the more complex InTEC model. And secondly, the crude method is site-specific since the measured rates were taken directly from previous research in Guizhou province. The equation to calculate the amount of CO_2 is

$$C_s = P_s \times A_s \times Y, \tag{1}$$

where C_s is total CO_2 sequestered tree species s, P_s is the production rate of CO_2 for tree species s, A_s is the area in hectares for tree species s, and Y is the number of years.

In one of the model scenarios identified later in this paper, we allow for trees harvesting every 24 years. Following Xu (1995), we assume that not all carbon is released immediately at harvesting, but rather that much of it is stored in wood products and in litter, to be released slowly over a period of time. Xu (1995) provides the only estimates of the proportions and lifespans of various uses of timber in China.[3] For example, 7.4% of wood consumption is used in buildings and has an average lifespan of 80 years, while 4.8% of wood consumption is used for packaging with a lifespan of 5 years. Xu (1995) also suggests that litter accounts for 15% of the total tree biomass, with a lifespan of 5 years. We calculated the amount of carbon sequestration after harvesting in year 24 by first adding the carbon sequestered in newly planted trees in year 25 to the amount of carbon sequestered over the previous 24 years. From this figure, we subtracted the amount of carbon released from wood products and litter within 1 year of harvesting. We then repeated this process for every subsequent year.

4.4. The crop income model

Information about crop income is necessary for calculating the opportunity costs of lost crop income from the reforested sites. The values produced for crop incomes are based on the 2004 survey conducted in Liping. However, not all crops were reported on in each township and different areas of crops were planted for different townships. The following values by crop type were calculated from the survey data: total area per crop per township, productivity rates (kg/ha) per crop, crop market price (RMB/kg), expenses (RMB/ha), and net income (RMB/ha) per crop. Productivity rates were created for each crop by

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[3] Xu's data are over 10 years old. Given the rapid rate of economic development in China in the intervening period, it is quite possible that some of the timber allocations may have changed, such as the percentage of timber used for building construction. The estimates of lifespans are less likely to have changed.

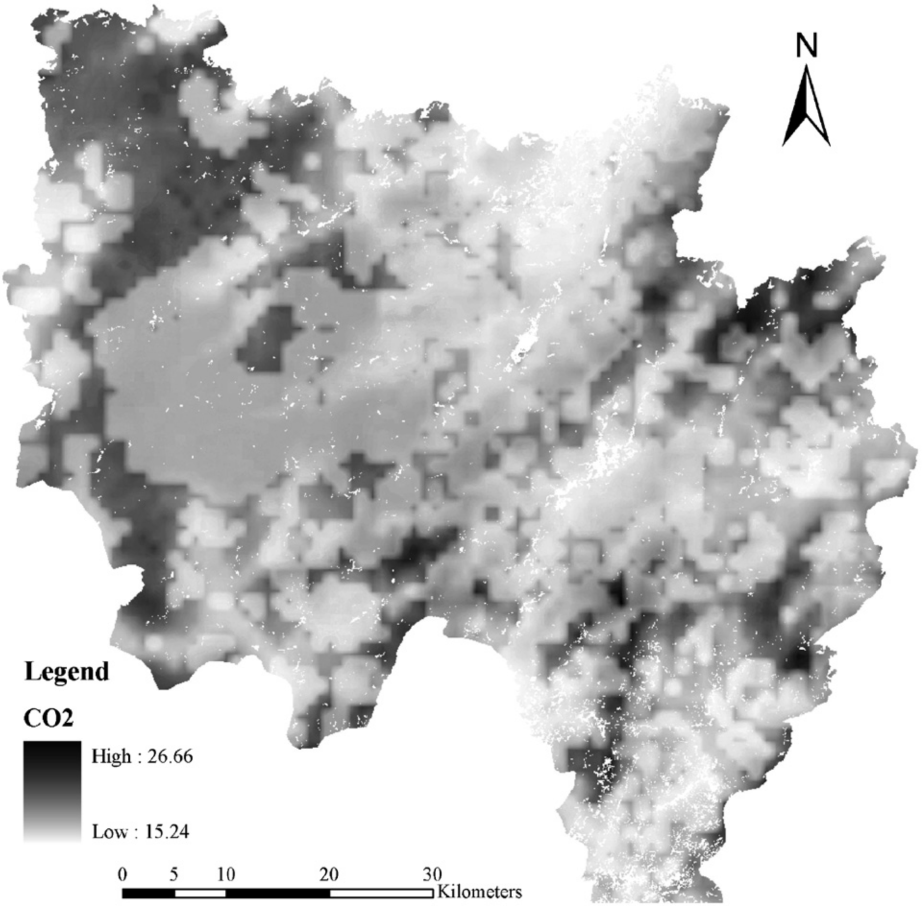

Fig. 5. Cumulative CO_2 for deciduous trees from InTEC model in kg/m^2, with a resolution of 90 m, for the years 2003–2050.

Table 2
Crude NPP rates for tree species in Guizhou Province

Forest	Production (tonnes CO_2/ha/year)	
	Range	Mean
Evergreen broadleaf forest	6.96–14.98	9.93
Temperate-coniferous forest	1.63–6.88	4.49
Warm-coniferous forest	2.04–13.45	6.09
Bamboo forest	3.20–21.88	9.62

finding the overall average for each crop across all townships. Crop market prices were also based on overall averages across all townships. Although prices and expenses may change over time, we assume, for the purpose of simplification, that they are constant. Twenty-three out of 621 crop productivity and market price values were excluded because they exceeded the others by a magnitude of 100 or more and were assumed to be errors. Finally, crop production expenses were calculated by summing up all the expenses for a particular plot and dividing by the area of the plot to give a value in RMB/ha, and then taking an average of this value across all the plots in a township for a specific crop. The expenses consist of the cost for seeds, fertilizer, pesticide, irrigation, work animals, and machinery. The cost of human labor was not included since the survey only reported the number of days worked and not the actual cost. The average net income for a crop was calculated by the following formula:

$$\mathrm{NI}_i = (\mathrm{CP}_i \times P_i) - E_i, \tag{2}$$

where i is the crop type, NI_i is net income, CP_i is crop price, P_i is crop productivity, and E_i represents the average expenses for the crop. The net crop income values are an average across all townships that reported on those specific crops.

Although rice is a common crop across all townships, there is considerable variance in crops among townships. To account for this variance, an additional net crop income value was created that was specific to each township. The section of the survey on the Grain for Green program asked for both the area that had been reforested and the old crop that was grown before reforestation. Using the total area of each old crop, a ratio of crops was developed by township. By multiplying the proportion, by area, of the old crop grown in the township by the net crop income rate, a net ‘‘basket of crops’’ income value was created for each township:

$$\mathrm{BC}_t = \sum_i (\mathrm{CR}_{i,t} \times \mathrm{NI}_{i,t}), \tag{3}$$

where BC_t is the net "basket of crops" income per hectare for township t, $\mathrm{CR}_{i,t}$ is the proportion of old crop i grown in township t and $\mathrm{NI}_{i,t}$ is the net crop income from crop i in township t. The net "basket of crops" income rate represents a township-specific income rate based on lost crop area. Since only 19 of the 25 townships were surveyed, a county-wide net "basket of crops" income rate was also calculated, based on township-wide ratios of lost crop areas of land. This county-wide rate is used for townships for which there was no township-specific rate available.

To calculate income from crops for a single year, the township rates were multiplied by the area of reforestation for each township. Afforested areas were not included, since these are not cropland before trees are planted, and therefore do not represent either lost crop income or possible Grain for Green subsidies.

4.5. The timber income model

The value of timber per unit volume falls into different price categories that are dependent on four factors: tree species, length, diameter, and quality. Due to a limited amount of growth information, only two tree species can be evaluated in the timber income model—Masson Pine and Chinese Fir. Deciduous tree data are available for volumes, but not for growth rates.

For simplicity, we assumed that all reforested areas were planted with Chinese Fir and all afforested areas with Masson Pine. Using a conservative log length of 5.8 m and an average diameter of 16 cm, the volume of a single log for either Masson Pine or Chinese Fir at 24 years of age would be $0.117\,\mathrm{m}^3$. A rotation length of 24 years was chosen because it is not untypical for the species and it matches the model simulation to the end of 2050, allowing for exactly two harvests. Given a typical stand density of 75–150 trees/ha (Clifton and Perry 1999), which assumes that the forest is being managed for timber production, a median value of 112 trees/ha is used to calculate potential timber values. The tree income is simply the product of the number of trees, a single tree volume, and the timber price. The market prices for medium quality (quality level #2) Chinese Fir and Masson Pine are 344 and $192\,\mathrm{RMB/m}^3$, respectively.

According to the household survey, 17% of the trees planted under Grain for Green were bamboo. However, a timber income scenario using bamboo was not created for four specific reasons. The first is that bamboo tends to be an input-intensive tree crop, requiring high inputs of fertilizer, and the high rate of CO_2 sequestration during growth is offset by the economic and environmental costs of these inputs. The second is that bamboo grows quickly, and is harvested on a regular basis, which adds extra complexity to the model. Third, the InTEC model does not support a bamboo species in the NEP modelling, so there would have been no way to compare the results from the InTEC model and the crude rates. Finally, bamboo grows in a symbiotic relationship with fungus, and can be difficult to establish compared to other tree species.

Although we assume that timber income only becomes available at harvesting in year 24, some timber income could be produced through thinning operations before that point. We therefore assume that any revenues obtained from the sale of trees before stand harvesting occurs are used to cover forest management (i.e. maintenance) costs.

4.6. The carbon credit model

Once all other calculations are finished, carbon credits are the easiest to calculate since they are based on the tonnes of C sequestered multiplied by a CO_2 conversion factor (one tonne of carbon is equivalent to 3.6667 tonnes of CO_2) and then by the price per tonne of CO_2. Market prices in the European Union were at all-time lows at the time of this study, trading close to €6.75 per tonne of CO_2 (www.pointcarbon.com,2005). However, some predictions suggest that values of €16–19 are a reasonable range (Baron, 2002), and the true price of CO_2 could be much higher, up to €200–270 (www.eia.doe.gov,2002). Similar to other model components, the carbon credit can be calculated by township or for the county as a whole. Two different values for carbon credits are used in the IA model, €6.76 and €18 per tonne, to reflect the bottom range of current CO_2 market valuations.

4.7. The grain for green model

The Grain for Green program provides annual grain subsidies to farmers who have participated in the reforestation of their cropland. The current subsidy is 2250 kg grain (rice)/ha. At the 2004 market price of rice at 1.04 RMB per kg, the value of the 2250 kg of grain is 2340 RMB/ha. Given the area of reforested land per township, the resulting income in grain can be calculated. There is an additional Grain for Green subsidy in cash for both afforested and reforested land but, for simplicity, this was assumed to cover the cost of planting and maintenance (both material and labor costs). The grain and cash subsidies end after 8 years.

Our income calculations do not include the potential indirect income benefits of Grain for Green, such as additional off-farm income from those members of the household freed from agricultural labor on reforested lands. Although the household survey did not collect information on quantitative changes in off-farm income, it did ask about qualitative changes (i.e. increases, decreases or no change in off-farm labor) and the percentage of households reporting an increase in off-farm labor (24%) was slightly higher than the percentage reporting a decrease (13%). On the other hand, almost half of the households (47%) reported an increase in their workload for raising livestock, suggesting that farmers transferred more freed labor to livestock income production after Grain for Green than to off-farm income production.

Quantitative estimates of income changes from the study by Uchida et al. (2005) on Grain for Green impacts in Guizhou and Ningxia provinces offer insight into the relative importance of indirect income benefits. In their study of Ningxia and Guizhou provinces, they found that the relative contributions of increases in off-farm work and livestock production to increases in household income after Grain for Green were fairly small. One year into program implementation, the number of households receiving income from off-farm labor and from livestock-raising had increased by 5% and 8%, respectively, in Ningxia and very little in Guizhou.

4.8. Scenario creation

For illustrative purposes, four scenarios were created, as summarized in Table 3. Each scenario is based on the use of the 2003 sites for reforestation and afforestation and is for the years from 2003 to 2050. The locations of the reforestation sites for 2000–2002 were not included because they are not currently available electronically. The scenarios were designed to produce a range of results for both CO_2 and income, on both a township basis and county-wide. Scenario #1 represents the most conservative outlook, with no harvesting of timber, no CO_2 market (and hence no revenue from the sale of carbon credits), and no continuation of the Grain for Green subsidies. Scenario #2 incorporates a lower bound CO_2 credit value (€6.75/tonne), assumes no timber harvest, and is the only scenario to use a county-wide, lost crop net income rate. Scenario #3 is the only scenario to incorporate a timber harvest and uses the lower bound CO_2 credit value. Scenario #4 is the optimistic scenario, with a high CO_2 credit value (€18/tonne) and continuing Grain for Green subsidies. All scenarios include afforestation sites in the CO_2 credit estimates but not in the lost crop income.

The CO_2 sequestration estimates use both the InTEC and crude methods and, except for Scenario #3, different tree species were used for the reforestation and afforestation areas. Scenario #3 uses only the coniferous tree species group, but different coniferous species (Chinese Fir and Masson Pine) are grown on the reforested and afforested land in order to explore the impact of different timber prices of these two species on incomes. The crude method used the average CO_2 sequestration rate from Table 2.

In Scenarios 1, 2 and 3, the Grain for Green grain subsidies and cash payments to farmers expire after 8 years. For the optimistic Scenario #4, we assume that the Grain for Green grain subsidy on reforested sites continues indefinitely, at least for the duration of the model, but that the cash payment of 750 RMB/ha for maintenance on both reforested and afforested sites stops after 8 years.

A timber market is only used for one of the scenarios, since the economic returns from timber forests are infrequent. As well, CO_2 sequestration is greatly reduced when the biomass is eventually harvested and the land is disturbed.

We present total net income from two perspectives: that of the farmer and the state. The sources of net income for the farmer are Grain for Green grain subsidies, timber income and lost income from converted cropland. The sources of net income for the state are carbon credits and expenditures for grain subsidies and cash payments to farmers.

Benefits or losses in the future are not worth as much as present benefits or losses, so a simple way to compare the four scenarios is to examine the net present value (NPV) of the scenarios. The discounted total net income is calculated for each year and summed up to show the net present value of the scenario. This amount is also calculated per hectare. The following equation calculates the NPV:

$$\mathrm{NPV}_n = \sum_{t=1}^{n} \frac{\mathrm{TNI}_t}{(1+r)^t}, \tag{4}$$

Table 3
Scenario configuration

		(1)—Conservative	(2)—Median	(3)—Timber-based	(4)—Optimistic
CO_2	Method	InTEC	Crude	InTEC	Crude
	Reforest	Coniferous	Temperate coniferous	Coniferous	Deciduous
	Afforest	Deciduous	Warm coniferous	Coniferous	Warm coniferous
Crop	Method	By township	County-wide	By township	By township
	Crops	Various	Corn, pepper, potato, rice, rapeseed, soybean, watermelon, yam	Various	Various
Timber	Harvested	No	No	Yes	No
	Species	N/A	N/A	Reforest—Chinese Fir, Afforest—Masson Pine	N/A
CO_2 credit	Included	No	Yes	Yes	Yes
	Price	No	€6.75 (73.2 RMB)	€6.75 (73.2 RMB)	€18 (195.3 RMB)

where NPV_n is the net present value to the year n, TNI_t is the total net income for year t, from the sources described above, and r is the discount rate. We use a discount rate of 3.24% (pbc.gov.cn, March 2004).

4.9. Gender and ethnicity

In order to determine whether the Grain for Green program had already had and might continue to have differential impacts by gender and ethnicity, we examined the household survey responses to questions about the impact of the program on workload. The series of questions asked whether, after the introduction of the program, any household members had experienced a change in workload for the following tasks: cropping, livestock management, fuel wood collection, forest conservation, off-farm work, child-rearing and housework.

Our research on the impact of Grain for Green by ethnicity was exploratory in that we did not have any preconceived hypotheses about the nature of those differences. On the other hand, the extensive literature on gender roles in China provides a basis for developing hypotheses about gender differences. We anticipated that all respondents, particularly men, would report a decrease in cropping workload (and hence availability of more time for other activities) and an increase in forest conservation labor because of the conversion of croplands to forests. We expected that women, who are traditionally responsible for fuel wood collection, would report no immediate change in their fuel wood collection workload because fuel wood availability on the reforested and afforested sites would not increase for a number of years. We expected an increase in workload for livestock management for both men and women since the extra time that they had available would allow them to raise more livestock. We felt that men would be more likely to engage in increased off-farm work. We expected that women would spend more time devoted to child-rearing and housework, both traditional roles for women.

5. Analysis of results

The analysis of results covers outputs from all of the model components, and as such will be discussed in order of processing. A broader analysis of scenario outcomes, and implications for decision-making, follows discussion of the specific components.

5.1. CO_2 outputs

Table 4
CO_2 sequestration from 2003 reforestation and afforestation sites to 2050

Tree species (group)	InTEC method		Crude method	
	Tonnes CO_2	CO_2/year/ha	Tonnes CO_2	CO_2/year/ha
Deciduous	457,072	3.80	1,192,982	9.93
Coniferous	439,089	3.65		
Coniferous (temperate)			539,425	4.49
Coniferous (warm)			731,648	6.09
Area (ha)	2502.9		2502.9	

The summary of CO_2 sequestration amounts as calculated by the InTEC and crude methods (see Table 4) reveals that there are significant differences between methods and within methods depending on the choice of tree species or tree species group. Most notably, for deciduous trees, the InTEC model returned an amount of 457,072 tonnes of CO_2 over 48 years, compared to 1,191,438 tonnes using the crude method, an amount that exceeds the InTEC results by 160%. The crude estimates are higher because they are based on NPP rather than NEP that was the output from InTEC. It is expected that the NEP would be considerably smaller than NPP because of the heterotrophic respiration in forest soils that was simulated by InTEC. The crude estimate of carbon accumulation is the annual increment of biomass, which is also smaller than NPP because part of the biomass created by NPP, e.g. leaves and fine roots, would turn over to soil and becomes the organic matter. Therefore, the ultimate difference between the crude estimate and the InTEC estimate is in the soil carbon accumulation. The crude method ignores the possible changes in soil carbon reduction or accumulation and therefore could be in considerable error. This method is used here because these estimates from biomass increment are more readily available from inventory data than data required for running a process-based model such as InTEC.

The InTEC model has a clear advantage in that it can simulate a range of effects such as climate, and incorporates inputs such as soil type and elevation. It would generally be more accurate than the crude method because it can consider all major factors influencing soil carbon accumulation and decomposition. The model's ability to simulate soil carbon pools has been validated through a parallel study at this site (Shao et al., 2007).

5.2. Crop income outputs

Not surprisingly, the most common crop in Liping by area of land cultivated is rice, which accounts for over 55% of reported cropland in the survey. However, for the Grain to Green program, rice cropland was seldom chosen to be reforested. Instead, the most common crops that were replaced by trees were rapeseed (canola), yam and corn (see Table 5). Together these three crops account for 50% of land reported reforested in the survey. The calculated net income rate from the Liping survey was 1059 RMB/ha for rapeseed, 1995 RMB/ha for yam, and 1350 RMB/ha for corn. By comparison, rice had a calculated net income of 3843 RMB/ha, double that of yam, almost triple that of

Table 5
Old crop percentages by area for reforestation sites among surveyed households

Crop	Area (ha)	%
Corn	21.73	15.3
Pepper	2.20	1.5
Potato	12.23	8.6
Rapeseed	27.13	19.1
Rice	2.55	1.8
Soybean	11.13	7.8
Watermelon	5.08	3.6
Yam	22.90	16.1
Total		73.8

corn, and more than triple that of rapeseed. These crops were good candidates for reforestation since the loss of income per hectare would be much lower than for a crop like rice.

The method used for applying the calculated net incomes from the survey to the 2003 reforested plots affects the total income result. These methods were necessary since the survey-based crop incomes must be extrapolated to all the reforestation sites in Liping. The method that uses the net income of a basket of crops specific to each township resulted in a yearly net income loss, before subsidies, across all reforested plots of 2,755,581 RMB. Based on the net income basket of crops for the entire county, the calculated yearly net income loss was 2,593,184 RMB, a drop of 5.9%. Similarly, different assumptions about the types of crops formerly grown on converted land would have different impacts on income. For example, if all the reforestation sites were changed from rapeseed, then the total yearly net income loss would be 1,660,262 RMB. Conversely, if all the reforestation sites were formerly producing yam, the yearly net income loss would be 3,349,813 RMB.

Under the Grain for Green program, farmers receive a subsidy of grain equivalent to 2340 RMB/ha. Interestingly, the county-wide net crop income was 1698 RMB/ha, which means that, on average across all of Liping, farmers are better off since they receive 2340 RMB/ha under the Grain for Green program, or a net gain of 642 RMB/ha. Given the potentially reduced labor inputs required for growing trees, farmers are considerably better off under the Grain for Green program for as long as the subsidy is provided.

Analysis at the county level can obscure important differences that occur at a township level. The farmers are not always better off when compared township by township (see Fig. 6). While most townships have a positive net income under the Grain for Green program, before subsidies cease, farmers in two townships, Bàzhài and Défèngzhēn, experience a net loss of income because they lose high-income cropland to the reforestation program.

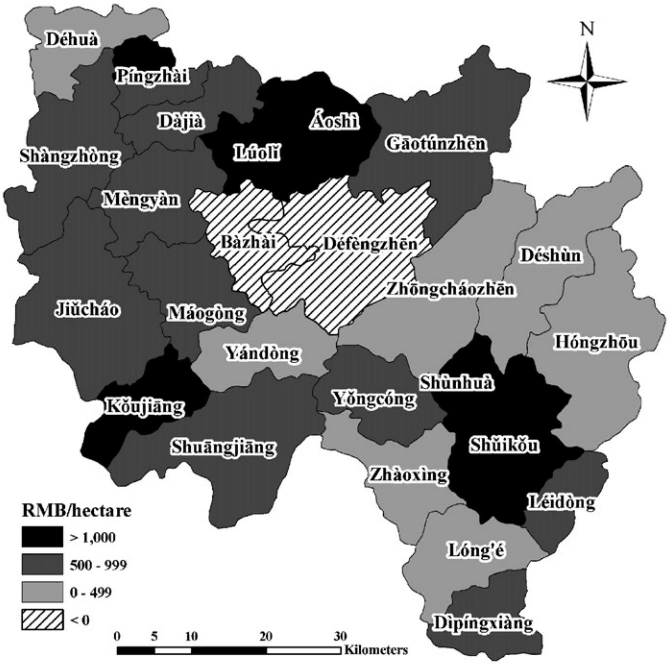

Fig. 6. Annual net income rates on reforested plots under Grain for Green by Township.

5.3. Timber outputs

The timber income calculations have a high degree of uncertainty due to issues such as unknown future market prices, forest management techniques, pest infestations and forest fires. Also, timber incomes vary widely depending on the number of viable trees for harvesting in an area, tree species, and quality of tree. In Scenario #3, the total timber income on reforested lands (from two harvests) is about double that on afforested lands, but on a unit area basis, the income from planting Chinese Fir on reforested lands is 8355 RMB/ha while planting Masson Pine on afforested lands generates 7110 RMB/ha.

5.4. Carbon credits

The potential for carbon credits could be a deciding factor in the success of an ecologically driven forest management system for Liping, particularly if the income from carbon credits is distributed at the county, township and individual farmer levels. However, the likelihood of this local distribution occurring is questionable. Besides the distribution issue, the potential contribution of carbon credits will depend on the value of CO_2 on the market. Using the current market price of carbon in the European Union of €6.75 per tonne, the value of CO_2 added through trees planted in Liping during 2003 (CO_2 based on coniferous trees using the InTEC model) would have resulted in only 457.5 RMB/ha for 2004, but would rise to 1075.5 RMB/ha by 2020. A higher credit value of €18 would give 1218 RMB/ha in 2004 and 2866.5 RMB/ha in 2020. Using the crude method for warm coniferous forest (6.09 tonne CO_2/ha/year) yields an income of 4362 RMB/ha in 2020 with the carbon price set at €18.

5.5. Scenario outcomes

Table 6 shows the values, totalled for all of Liping, for area planted, CO_2 sequestered, lost crop revenues, Grain for Green subsidies, timber income, and the CO_2 credits. Table 7 shows the discounted income values for each scenario for all of Liping. Fig. 7 shows the township-by-township results. The range of outcomes within these four scenarios is significant, since it demonstrates how different assumptions about timber or CO_2 markets and choices of modelling methods impact the outcome. From an economic standpoint, only Scenario #4 (continuing subsidies) yields a positive result for farmers within the 48-year time frame of the IA model, with a county-wide average NPV farmer income of 13,590 RMB/ha over 48 years. The biggest loss for farmers for all of Liping County is under Scenario #1 (no subsidies, no timber income) with an NPV loss of 28,050 RMB/ha over 48 years. This loss may seem relatively small, but recall that under Scenario #1, farmers receive subsidies for the first 8 years of the scenario and that all but two townships experience positive net incomes during that period. Therefore, the NPV of farmer incomes during the first 8 years is quite high, but declines steadily after that as future losses are discounted back to the present. At an average conversion area per farmer of 0.4933 ha, the amount lost per farmer over 48 years is about 13,838 RMB under Scenario #1. The state sees positive returns only for Scenarios #2 and #4. Scenario #1 produces negative returns because there are no state revenues in Scenario #1, only expenses in the form of Grain for Green payments. Scenario #3 produces negative returns because of the diminished value of carbon credits available when timber harvesting takes place.

The township-by-township results illustrate significant differences in the township income rates. Under Scenario #2, all townships have the same rate of income per hectare because the county-wide "basket of crops" value was used to calculate lost crop revenues. Under Scenario #1, farmers in Shǔikǒu are best off, or least worse off, losing a NPV income of 10,020 RMB/ha over 48 years, while the farmers in Défèngzhēn are worst off, losing a NPV income of 81,405 RMB/ha. The same situation occurs in Scenario #4, where again the farmers in Shǔikǒu are best off with an NPV income of 31,620 RMB/ha over 48 years, while the farmers in Défèngzhēn lose an NPV income of

Table 6
Results from scenarios

		(1)—Conservative	(2)—Median	(3)—Timber	(4)—Optimistic
Area	(1) Reforestation (ha)	1528	1528	1528	1528
	(2) Afforestation (ha)	972	972	972	972
CO_2 (tonnes)	Reforestation	264,909	329,241	73,335	728,144
	Afforestation	182,389	284,135	48,026	284,135
	Total	447,299	613,376	121,361	1,012,279
Lost crop net income	(3) Total (RMB)	−132,267,889	−124,472,851	−132,267,889	−132,267,889
Grain for Green	(4) Cash-equivalent of grain stipend (RMB)	28,597,795	28,597,795	28,597,795	171,586,771
	(5) Cash payment (RMB)	15,000,000	15,000,000	15,000,000	15,000,000
Timber income	(6) Reforestation (RMB)	0	0	12,769,754	0
	(7) Afforestation (RMB)	0	0	6,903,648	0
CO_2 credit	CO_2 price (RMB/tonne)	0	73.2	73.2	195.3
	(8) Reforestation (RMB)	0	88,368,361	19,683,073	521,423,818
	(9) Afforestation (RMB)	0	76,261,843	12,890,104	203,469,103
Total incomes	(10) Farmers (RMB), 48 years = (3) + (4) + (6) + (7)	−103,670,094	−95,875,056	−90,900,339	39,318,882
	Farmers (RMB/ha/48 years) = (10)/(1)/15	−67,845	−62,745	−59,490	25,725
	(11) State (RMB), 48 years = (5) + (6)−(2)−(3)	−43,597,795	121,032,409	−11,024,618	538,306,150
	State (RMB/ha/48 years) = (11)/((1) + (2))/15	−17,445	48,420	−4410	215,325

Table 7
Scenario results adjusted to net present value with a discount rate of 3.24%

	(1)—Conservative	(2)—Median	(3)—Timber	(4)—Optimistic
Farmers (RMB), 48 years	−43,155,607	−39,100,861	−38,662,485	20,452,509
Farmers (RMB/ha/48 years)	−28,050	−25,590	−25,110	13,590
State (RMB), 48 years	−22,678,271	62,840,457	−3,305,583	279,045,432
State (RMB/ha/48 years)	−9075	25,140	−3405	111,630

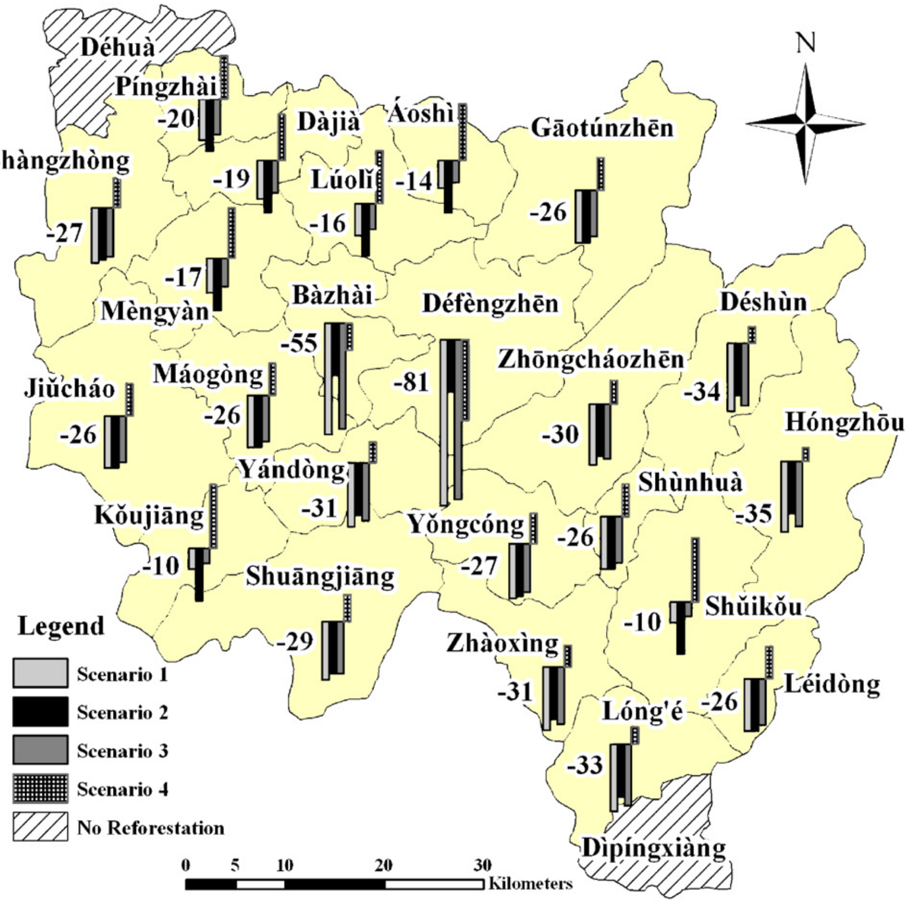

Fig. 7. Comparison of scenario outcomes, in NPV income by Township (RMB/ha) over 48 years (number is thousands of RMB/ha for the bar on the left-side).

39,780 RMB/ha over 48 years. While the average gain for a farmer under Scenario #4 is an NPV income of 13,590 RMB/ha over 48 years, some farmers are much better off while other farmers, specifically those in Défèngzhēn and Bàzhài, see a loss (see Fig. 7). As noted earlier, the farmers in these two townships have lost high-income cropland to the reforestation program. In Défèngzhēn, 72% of the cropland converted to forest was used to grow watermelons, a high-income crop returning 4528.5 RMB/ha.

The issue of distribution of income is significant, since Scenario #2 produces a loss for farmers of NPV 39.1 million RMB. Meanwhile the state receives an NPV income of 62.8 million RMB. Conversely for Scenario #4 the state receives an NPV income of 279.0 million RMB because of the substantial CO_2 credits, while the farmers receive an NPV income of 89.3 million RMB because the Grain for Green subsidies continue indefinitely. Scenarios 2–4 demonstrate that the money to cover the cost to the state of the Grain for Green program could be covered by the CO_2 credits, with money left over. From an ecological perspective, Scenario #4 would be the most desirable since the trees are not cut for timber and the amount of CO_2 sequestered is the highest of all four scenarios (because of the planting of deciduous rather than coniferous trees on reforested land), while Scenario #2 is second best for CO_2 sequestration.

5.6. Outcomes by gender and ethnicity

The majority of those responding to the household survey were the Dòng minority people, at 88%, with 10% Miáo and only 2% Hàn. The ethnic minority of the Dòng are in the majority compared with the predominant Hàn Chinese. The survey results are fairly representative of the statistics for Liping, which state that 92% of the county's population consists of minority peoples (Liping Statistics Bureau, 2003). We tested for differences in workload impacts attributable to Grain for Green among the Dòng and Miáo only, since the Hàn were not present in sufficient numbers among those surveyed to conduct valid statistical tests.

Using chi-squared statistical tests and a significance level of $\alpha = 0.05$, we found statistically significant differences by ethnicity for only two types of work: child-raising ($p = 0.023$) and housework ($p = 0.022$). In comparison to the Dòng, a higher percentage of the Miáo reported an increase in the workload for child-raising (33% versus 19%) and housework (25% versus 15%) and a lower percentage reported no change in workload. These findings suggest that further research is needed to determine why such differences occur.

Surprisingly, none of the chi-squared tests run for detecting gender differences in workload changes were statistically significant. However, we were concerned that, since the survey respondents were primarily male, their responses could have produced a systemic under- (or over) estimate of perceived workload changes among females. Thus, we conducted chi-square tests to see if, for male or female family members, the sex of the respondent (male or female) had an impact on the response to whether the workload had increased or decreased. Only the male and female heads of household were considered, and the chi-square test was run twice; once for perceived workload changes among female heads of household according to whether a male or female responded to the survey, and once for perceived workload changes among male heads of household according to whether the survey was from a male or female respondent. Of the 16 different chi-square tests, four tests produced statistically significant relationships: two for male heads of household with livestock and housework, and two for female heads of household with cropping and livestock (Table 8). Male respondents were more likely than female respondents to say that, after Grain for Green, the workload for male heads of household in livestock-raising increased (52% of male respondents reported an increase versus 17% for female respondents). When asked about livestock-raising by female heads of household, the perception of workload changes also differed significantly by sex of the respondent, although not as much as for perceived workload changes for male heads of household. Men were again more likely than women to say that workloads for livestock-raising increased after Grain for Green (53% of male respondents reported an increase versus 33% for female respondents). The results suggest that either male respondents are overestimating workload increases in livestock-raising for both men and women or that female respondents are underestimating workload increases. In either case, there is a clear difference in perceptions, by gender, about workload changes for men and women, at least for livestock-raising.

There were also differences in perception by gender for two other activities: crop production and housework. Although there was no difference between male and female respondents in their perception of workload changes in crop production for men, there was a difference in perceived changes in crop production for women. Ninety percent of the female respondents felt that there had been a decrease in crop production workload for female heads of household after Grain for Green, while only 59% of male respondents thought that female workload had decreased. Similarly, although there was no difference between male and female respondents in their perception of workload changes in housework for women, there was a perceived difference in housework changes for men.

These results indicate that, in some cases, the sex of the respondent can have an impact on the reported change in workload. There is no general trend in the responses. In once case, namely livestock raising, female respondents were more likely to report decreased workloads for both the female and male heads of household after implementation of Grain for Green than the male respondents. In two other cases, namely for crop production and housework, female respondents were less likely than men to report decreased workloads after Grain for Green. Further research is required to determine the source of these gender-influenced perceptions. It may be related to prior responsibilities, by gender, for various types of work on the farm in the in the home. It may be related to the size and

Table 8
Gender differences in perceived workload changes after the Grain for Green program

Type of workload	Sex of survey respondent	Workload change			Chi-squared significance
		Increase	No change	Decrease	
Crop work by female head of household	Male	92 (41%)		134 (59%)	$p = 0.019$
	Female	2 (10%)[a]		19 (90%)	
Livestock work by female head of household	Male	119 (53%)	81 (36%)	26 (12%)	$p = 0.000$
	Female	7 (33%)	5 (24%)	9 (43%)	
Livestock work by male head of household	Male	125 (52%)	91 (38%)	25 (10%)	$p = 0.002$
	Female	3 (17%)	9 (50%)	6 (33%)	
Housework by male head of household	Male	40 (17%)	108 (45%)	93 (39%)	$p = 0.026$
	Female	1 (6%)	14 (78%)	3 (17%)	

[a] Valid chi-squared test not possible without combining categories, due to small number of female respondents.

structure of the household. At the very least, our results highlight the importance of searching for gender differences in program impacts.

6. Model improvements

The most obvious area of improvement for this IA model is to incorporate additional data, specifically soil data, especially for CO_2 sequestration; additional tree species information, including bamboo and economic trees; and tree-planting details and management practices, including density of trees planted and thinning regimes. Bamboo could be a particularly important tree species to consider since, despite its more uncertain CO_2 sequestration benefit, it can have a significant economic impact. For example, in Linan County, Zhejiang Province, bamboo crops provided 1/3 of a farmer's income in 1996, with a total income county-wide of over US $61 million (Kant and Chiu, 2000, p. 288). Another improvement would be to add the capacity for modelling agroforestry practices.

Modelling an entire ecosystem, such as the InTEC model does, results in many different opportunities for errors. Firstly, the use of accurate input data for soil, elevation, species map, and productivity is essential for reliable model outputs. If the input species map is incorrect, then the wrong tree types will be used to calculate NEP. Since CO_2 sequestration rates vary widely between species (see Table 2), it is essential to use the correct species. The InTEC model only produced results by species group, so species-specific CO_2 sequestration rates are obscured. Also, the model assumes a homogeneous landscape. For tree plantations that replace cropland with only one tree species, this type of landscape would be correct. A wider variety of trees have been planted on reforestation sites in Liping, but no data are available yet on the characteristics of those species. Additionally, any combination of species on a site would complicate the model. Also, NEP will depend on the density of trees over time. Not only does the initial planting and resulting survival rate need to be incorporated into the model, but differing forest management practices must also be modeled, an issue not covered by this research.

Using the crude method of CO_2 sequestration estimation has equally serious potential sources of error. Most important is choosing the appropriate rate of CO_2 sequestration from the range of values given for a specific tree species. Also, the impact of varying climate, elevation, soil, and density is not explicitly represented. Lastly, the most serious issue with using the crude method is that it only models biomass accumulation, which is NPP less turn over of roots and leaves to soil. It is always larger than NEP, and the crude method could heavily overestimate the amount of CO_2 sequestered.

In the long term, and with improvements, the InTEC model or an InTEC-based model is the preferred method for calculating CO_2 sequestration. This is because the InTEC model can incorporate the effects of climate, elevation and soil into the modelling of CO_2 sequestration.

Future household surveys in Liping will need to ensure that a representative sample is used. While the support of local forestry officials was excellent, especially in arranging transportation and locations to conduct the survey, it is possible that bias on the part of the foresters in the selection of survey participants, unintentional or otherwise, was present.

While the issue of gender is not a significant factor in this IA model, there are some early indications from the household survey results that the experience of impacts from reforestation is felt or perceived to be felt differently by men and women. Without careful attention to the dynamics of gender in communities and households, the impacts of costs and benefits from forest development policy could easily be shared unequally between women and men.

7. Conclusions and future directions

There are two major results of the IA model and the scenarios presented in this research. The first result is the positive impact that the Grain for Green program has had for the farmers, especially in terms of financial support for the program and resulting increased income, at least in the short term. The other result is the predicted, long-term loss of income due to reforestation of cropland, once subsidies stop, a result that is strongly negative for the farmers. Under all three scenarios where subsidies end after 8 years, the farmers were always the biggest losers. Similar to our own findings, Ye et al. (2003) and Uchida et al. (2005) have identified the continuation of Grain for Green subsidies beyond 8 years as being critical to the success of long-term reforestation. If money received for CO_2 credits is shared with the farmers, perhaps in the form of continuing subsidies, then these negative impacts will be removed. However, since the CO_2 credits are available only when the stored CO_2 increases, and eventually a forest will reach equilibrium where no more CO_2 is being stored, the government cannot rely on these funds to continue subsidies in perpetuity. Alternatively, the money from the credits could be used to develop new and sustainable sources of income for the farmers. Experience elsewhere provides at least one example of how carbon credits can benefit local farmers. Costa Rica has a national forestry fund that has collected money from selling carbon credits, as well as a portion of the national fuel tax, and in turn distributed a portion of this money to local landowners in the form of an environmental service payment (ESP) (Miranda et al., 2002). The basis of these payments was a contract between the local landowners responsible for reforestation and the national forestry fund.

It is important to note that the outputs of this IA model do not include direct measures of a number of secondary benefits from reforestation and afforestation such as flood control and soil erosion control. Floods and soil erosion both have steep economic and environmental costs, and the added benefit of control of these effects is an additional issue that will need to be considered. In a review of 35 carbon sequestration studies worldwide, Richards and Stokes (2004) conclude that the secondary benefits (not including carbon credits) of cropland conversion may be as great as the costs, making carbon sequestration a no-regrets strategy. Another missing measure of benefits associated with Grain for Green is the potential increase in income from other sources that might result when excess labor is released from crop production on the converted plots.

Lastly, the demonstration of regional variation using a GIS-based spatial representation of incomes and CO_2 sequestration is an important result of this IA model. Outcomes from reforestation can vary widely among different townships (and households) within Liping, resulting in significant inequalities over time. Like the farmer from the newspaper article cited at the beginning of this paper, some households are losers in the implementation of Grain for Green, while others are being over-compensated. Disaggregated analysis of the type presented here is essential for capturing and remedying such inequalities.

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