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Distributed land use modeling and sensitivity analysis for REDD+

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ABSTRACT

There is an urgent need to develop a framework for understanding and predicting the effect of opportunity costs of REDD+. We develop an approach comprising two components: distributed land use modeling for assessing the profitability gap between maintaining palm oil plantations and complying with REDD+ and a sensitivity analysis of the model's predictions. First, a spatially explicit model is used to predict the future distribution of land use changes in central Kalimantan, Indonesia. This model predicts the change in carbon storage due to deforestation by linking business-as-usual baseline emissions scenario to historic data and using an improved cellular automaton system to predict land use changes. Input parameters include elevation, slope, aspect, soil types, distance to road, distance to river, etc. The so-called "ton-year approach" is combined with the future price of carbon to estimate compensation under the REDD+ mechanism. Potential revenues from palm oil plantation are calculated by multiplying yields from palm oil products with corresponding prices in the world market. Second, a sensitivity analysis is conducted to assess the robustness of the modeling results to alternative assumptions about palm oil price and carbon price. The palm oil price is shown to have the highest relative sensitivity. Further analysis indicates remarkable changes in the profitability gap depending on the price of palm oil; a change in palm oil price from $545.33 to $773.03 shows a large 155% increase in the profitability gap. Unfortunately, the most likely forecasts of palm oil prices continue to predict large differences in the profitability gap, favoring palm oil plantation over REDD+ projects. Thus, the effect of carbon pricing policies, as they currently stand, will remain limited.

Introduction

Tropical forests are known to play an important role in the global carbon budget because they contain about as much carbon in their vegetation and soils as do the temperate and boreal forests combined (Melillo et al., 1993; Dixon et al., 1994; Field et al., 1998). Recent estimates suggest that the carbon released from deforestation activities in the tropical region accounts for approximately 15–17% of anthropogenic emissions of carbon dioxide (CO_2) every year (IPCC, 2007; Van der Werf et al., 2009). However, carbon releases attributed to deforestation activities are not addressed in the Kyoto Protocol, which is regarded as a first step towards a truly global emissions reduction regime that would stabilize greenhouse gas (GHG) concentrations (UNFCCC, 2010). Growing global awareness of this issue has led to an increased focus on the role of tropical forests in carbon budgeting under the United Nations Framework Convention on Climate Change (UNFCCC). During the fifteenth session of the Conference of the Parties (COP 15) in December 2009, the Parties agreed that reducing emissions from deforestation and forest degradation (REDD) coupled with conservation, sustainable management of forests, and enhancement of forest carbon stocks (denoted together as "REDD+") in developing countries, through positive incentives under the UNFCCC, was a way of dealing with global GHG emissions.

However, proponents of REDD+ are facing a big challenge due to the booming demand for biofuels, which are regarded as an environmentally sustainable solution to the global energy crisis and a way to counterbalance global increases in CO_2 emissions. Such demand, especially for palm oil, appears to be driven by several factors: (1) the high cost of petroleum; (2) the ability to easily substitute palm oil for some biofuels and renewable; (3) efforts of food manufacturers in the United States to reduce the content of trans fats in their products using soy oil; (4) and the expansive economic growth in China and India, necessitating the need for palm oil (WWF-Indonesia, 2008). The formidable combination of improved agricultural technologies, enabling tenure and taxation policies, easy access to land (Cattaneo, 2007; Hecht, 2005; Morton et al., 2006), and the rising demand for biofuel feedstock, are said

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to have accelerated deforestation at the expense of forest carbon, native habitat, and forest biodiversity (Righelato and Spracklen, 2007; Koizumi and Ohga, 2007).

Like payments for environmental services (PES) (Angelsen and Wertz-Kanounniko, 2008; Angelsen, 2009), one of the key features of REDD+ is voluntary participation. PES mechanisms are designed to include schemes incorporating direct checks and balances on welfare and equity. The payment must be at least equal to the minimum willingness-to-accept of local communities or land users, measured by its opportunity cost (Bond et al., 2009; Wunder, 2009). The estimation of opportunity costs is important for two main reasons: to calculate fair compensation to land users for switching to forestry uses and to support low cost emission reduction strategies (Pirard, 2008). There is, thus, an urgent need to develop a framework for understanding and predicting the effect of opportunity costs of REDD+. This study uses simple assumptions that help to capture one of the important features of REDD+ schemes in Southeast Asia: land users' opportunity costs associated with palm oil plantation. An approach with two components was developed: distributed land use modeling for assessing the profitability gap between palm oil plantation and REDD+, and sensitivity analysis of the model's predictions.

Methods

Study area

The central Kalimantan province of Indonesia has recorded a rapid increase in areas devoted to palm oil plantation. Recent research shows that 763,000 ha of forest are directly threatened by future plantations (Forest Watch, 2007). Our study area comprises 47,940.75 ha (about 22.5 km long and 21.5 km wide) located in the north of Palangka Raya in central Kalimantan. As of the early 1990s, this area was covered by heath forest and peat swamp (Government of Indonesia/FAO, 1996), but has undergone extensive deforestation since 2000. Some researchers (Kanninen et al., 2007) classify the forest's transition in this area to be in the "forest frontier" stage, meaning that forest clearance will reach its maximum limit in the next 30 years, and large palm oil plantations are expected to usurp the land.

Baseline mapping

A REDD+ "baseline" is defined as expected or business-as-usual (BAU) emissions of CO_2e (GHGs measured as equivalent units of CO_2) from deforestation and forest degradation in the absence of additional efforts to curb such emissions (Griscom et al., 2009). In this study, we linked the BAU baseline emissions scenario to historic data. There were two main steps in baseline mapping: determining the deforestation rate and predicting potential locations of future deforestation.

For the first step, the annual rate of deforestation was estimated using a linear extrapolation of the historical rate. Landsat images of the study area in 2000, 2005, and 2009 were classified into six land use classes through the supervised classification method: dense forest, peat, sparse forest, plantation, road, and water. Conversions of dense forest, peat, and sparse forest were included in the "deforestation" category. The historical deforestation rate was calculated based on two land cover maps from 2000 to 2009 and using the formula developed by Puyravaud (2003). This formula is derived from the compound interest law and is more intuitive than the formula used by the Food and Agriculture Organization or FAO (1995).

$$r = \left(\frac{1}{t_2 - t_1}\right) \times \ln\left(\frac{A_2}{A_1}\right), \tag{1}$$

where A_1 is the forest area at the initial time t_1 (year 2000) and A_2 is the forest area at the final time t_2 (year 2009).

Then, an improved cellular automaton (ICA) system, in which the cell in the regular grid changes into a finite number of possible states according to a local interaction rule (Von Neumann, 1996; Wolfram, 1984), was utilized to predict land use changes. The CA system has been very successful in view of its operationality, simplicity, and ability to embody both logic and mathematics-based transition rules, thus enabling complex patterns to emerge directly from the application of simple local rules. It presents a powerful simulation environment represented by a grid of space (raster), in which the consequences of trends and policy interventions are visualized by means of dynamic year-by-year land use maps. In the practical application of this study, transition possibilities depended on the state of a cell (like forest or non-forest), and the state of its surrounding cells (such as elevation, slope, aspect, soil type, distance to road, distance to river/village, etc.).

Carbon credits

Total carbon emissions due to the plantations, $C_{f,net}(t)$, were calculated through changes in carbon stocks, as seen in Eq. (2). The components of this equation include (1) the initial conversion of the preceding vegetation into palm oil plantation, usually based on land clearing, denoted as $C_{f,clear}(t)$; (2) the decay of product, slash, and elemental carbon pools, denoted as $C_{f,decay}(t)$; and (3) the balance of emissions and absorption during the growth cycle of the oil palms, depending on the growth rate and management practices, denoted as $C_{f,regrowth}(t)$. Thus,

$$C_{f,net}(t) = C_{f,clear}(t) + C_{f,decay}(t) + C_{f,regrowth}(t), \tag{2}$$

where t is the year. According to the guidelines of the Intergovernmental Panel on Climate Change (IPCC, 2006), gains in carbon (C) are always depicted with a negative (−) sign, and emissions/losses, with a positive (+) sign. The emissions are converted to CO_2e by multiplying the value by 44/12 (stoichiometric conversion between CO_2 and C).

The distribution of carbon stocks in biomass for different forest types of tropical Asia (dense forest, sparse forest, or peatland) was used to determine the forest carbon losses (IPCC, 2006; Wahyunto et al., 2007; Slik et al., 2010). Carbon flux from the decay was derived from the response curve in tropical forests (Houghton and Hackler, 2001; Ramankutty et al., 2007). We adopted a palm oil allometric equation for calculating increasing carbon stocks from the growth of the palms, which is developed by measuring palm height, palm diameter, total number of leaves, frond base biomass, and frond biomass (Rogi, 2002; Dewi et al., 2009).

An effective REDD+ mechanism must provide continuous incentives for land users to maintain their forest lands. If successful, REDD+ would preserve forests during the risky development phase, much of it permanently (Chomitz et al., 2006). In order to ensure permanence and assign liability, the compensation fund would have to be paid annually for checking forest management practices on carbon accumulation, rather than verifying the existence of trees in the area and making a one-time payment. In this context, the so-called "ton-year approach," which had been discussed in the *IPCC Special Report on Land Use, Land-Use Change, and Forestry* (Watson et al., 2000), was adopted for estimating carbon credits.

In the ton-year approach, carbon credits are directly proportional to the project timeframe over which carbon is sequestered and are assessed in terms of the environmental and economic benefits of limited-term sequestration (MacLaren, 2000; Sedjo et al., 2001). In other words, it should be possible to define some measure of "equivalence" between temporary credits and permanent reductions that can be used to determine how temporary credits over different lengths of time compare in effectiveness to