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Forest vs. fuel – how could the politically fostered demand for energy crops influence the effectiveness of REDD+ instruments?

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Abstract: We present results from an agent based model that is designed to study the effects of different instruments for climate change mitigation. The policy instruments are a fostered demand for bioenergy and REDD+-like instruments that set incentives for land users to conserve carbon stock on their land. We test how the performance of these instruments is influenced by economic and ecological conditions of the region where they are applied. We find that for fostered demands for energy crops some designs of REDD+-like instruments are more effective than others. We also show that the effectiveness of the instruments depends on the economic site-conditions.

***Keywords**: Land use change, agent-based model, policy instruments, REDD+, bioenergy

1. INTRODUCTION

REDD+ is an instrument of climate policy that aims at the reduction of emissions from deforestation and degradation by preserving existing or establishing new forests as natural carbon sinks. Another incentive concerning land use decisions is set by the increasing demand for bioenergy. This is often politically fostered, for example through quotas, as a strategic response to challenges like increasing demand for energy, independence of fossil fuels, value addition in agrarian regions, and climate protection through the reduction of GHG emissions by the substitution of fossil fuels. Increasing the demand for energy crops, however, drives land use changes: through transition in the agrarian goods produced on arable land (shift towards energy crops) or/and conversion of land that had not been in agricultural use before but had been a major carbon store (e.g. fallow land, forests). These land use changes can lead to the reduction of the total carbon stock stored in vegetation and to higher greenhouse gas-emissions from land use (Fargione et al. 2008, Achten and Verchot 2011). But couldn't these side-effects of bioenergy production be mitigated by adding instruments as REDD+?

This directly leads to the following questions that are intensely debated but not fully answered so far (eg. Butler et al. 2009, Persson 2012, Killeen et al. 2011): To what extent will REDD+ - instruments be adopted in the presence of an increasing demand for bioenergy? What climate effects have to be expected when fostered demand for energy crops and REDD+ play in concert? What type of REDD+-

instrument would be the most effective to impede climate side-effects of bioenergy? Is there any dependence of the answers on the (economic and ecological) conditions in the region where the instruments are applied? We addressed these questions with an agent-based model of land use change. This modeling approach has been proven useful to foster understanding of the emergence of land use patterns through local autonomous decision making and has also been successfully used to study the impact of policies (Berger 2001, Matthews et al. 2007, Parker et al. 2003).

2. MODEL DESCRIPTION

2.1 Overview

2.1.1 Purpose

The aim of the model is to explore and to assess the performance of various instruments of climate policy (different types of REDD+-instruments, fostered bioenergy) in terms of their ability to reduce CO_2 emissions and to preserve terrestrial carbon-stocks under different ecological and economic site-conditions. This can be achieved by examining the land use patterns that result from the cultivation decisions of the agro-producers in the region. Hence, it is core to model the producers' decision-making that is driven by the markets for the agrarian goods of interest (esp. energy crops) and relevant policies (esp. climate policy). This can be done with a respective agent-based model that is coupled with a market-model.

REDD+ instruments aim to govern the ecosystem properties of carbon sequestration and storage. Thus it is crucial to be able to model the relevant ecosystem function. Thus the carbon balance of an agents` piece of land are is included in the model.

The model is a "toy model" that is rather abstract in order to reduce complexity drastically. The purpose of this type of model is system understanding and the generation of hypotheses.

2.1.2 Entities, state variables and scales

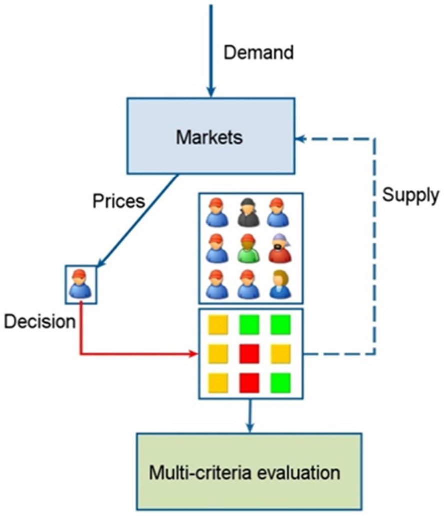

Figure 1. Overview of the model entities and processes

Figure 1 shows a schematic overview of the model entities and processes. A region is subdivided into cells. There is one agro-producer in each cell who has to decide over the agrarian good to be cultivated and sold at the market in the next step. Each cell contains a carbon stock that evolves over time depending on the land use implemented in the cell. Each agro-producer has to decide for one of three land use options in his grid cell. The options are: 1) cultivation of energy crops 2) cultivation of other agrarian commodities 3) no agricultural activity. All producers are assumed to behave as *Homo oeconomicus*, i.e. aim at maximizing their profits (cf. eq.1

in section 2.1.4). Their attribute is a cost function for the production of energy crops and for the production of other agricultural commodities. The cost function remains constant during the simulation (cf. eq.2 in section 2.1.4). Since the agents deliver the market supply and react to the price incentives from the markets there is an indirect interaction between them. The attribute of a market is the demand for the good that is traded on it. It also remains constant during the simulation (cf. eq. 3 in section 2.1.4). A grid cell is characterized by the current form of land use on it and by the size of its carbon stock (cf. eq. 8 in section 2.1.4).

Table 1. List of state variables (top) and parameters (bottom)

Symbol	Connotation	Range
State variables		
$p^j(t)$	Market price for j	
$h_i^j(t)$	Harvest of j in cell i	{0,1}
$cs_i(a)$	Carbon stock of cell i at time a	$[cb \ldots K]$
$T_i^j(t)$	Additional costs through taxes or political revenue	
Parameters economic model:		
i	Agent i	[0…100]
j	Product j	{0,1,2}*
D^0, D^1	Demand other agricultural products, Demand for energy crops	[0…180], [0…100]
c_i^j	Production costs of agent i	[0…1,8]
TC	Costs for changing production	0,1
τ	Tax rate	0,05
Parameters ecological model:		
ψ	Maximum carbon sequestration rate	[0…0,5]
K	Maximum carbon stock	100
e^j	Emission through the production of j	1
ε_{jL}	Further emission or emission reduction during the lifecycle of j	0,-0,25
cb	Carbon stock of a cell that is used for agricultural production	18

* 0 = Other agrarian production, 1 = Production of energy crops, 2 = No agricultural activity

2.1.3 Process overview and scheduling

Within one timestep prices for the different commodities are calculated based on current supply and demand, all agro-producers decide which land use option they choose in the next time step and the carbon stock of the cells is calculated. For their decision the agro-producers calculate the profits of the different land use options (including no agricultural activity with the consequence that the carbon stock in the cell is preserved and can grow). Then they pick the one with the maximum profit. The agents` decision determines the carbon stock of the cell in the next time step, thus coupling the human subsystem to the ecological subsystem.

When there is a certain policy instrument implemented, the agro-producers account for a tax as a cost or an incentive payment as revenue in their calculation. In the modelling framework, four instruments of climate policy are implemented: fostered bioenergy production modelled as increasing demand for energy crops and three REDD+-type instruments: (a) a tax for reducing the carbon-stock (Var I, cf. equation 5 in section 2.1.4), (b) an incentive payment for enhancing the carbon-stock (Var II, cf. equation 6 in section 2.1.4) and, (c) a combination of the latter two (Var III; cf. equation 7 in section 2.1.4). Tax and payment are set to be proportional to the carbon-stock respectively destroyed or build-up thus coupling the ecological to the human subsystem.

If there is no agricultural activity on a cell, we assume that a succession, which eventually leads to forest cover, takes place on it. So a carbon stock is build up over time. We represent this process by logistic growth of the carbon stock per cell (cf. equation 8 in section 2.1.4) since the general pattern of afforestation is that there is an increase in biomass over a length of time until a capacity is reached. When the agro-producer decides to use the cell for agricultural production, the vegetation is cleared and the carbon stored in it is released to the atmosphere. The carbon stock of the cell is reduced to the amount of carbon that is stored in the crops that are cultivated.

In order to evaluate the performance of the instruments of climate policy, the emissions from the region per time step are calculated (cf. equation 9 in section 2.1.4) and summed up to an atmospheric carbon stock that is used as evaluation criterion. The model is run for 20 timesteps in a situation without bioenergy. Then a demand for energy crops is introduced after which the model is run for another 50 time steps.

2.1.4 Submodels

The symbols in the equations are explained in Table 1.

Decision rule of the agents (profit maximization):

$$G_i^j(t) \overset{j}{\rightarrow} Max! \qquad (1)$$

with:

$$G_i^j(t) = p^j(t) \cdot h_i^j(t) - c_i^j - TC - T_i^j(t) \qquad (2)$$

Calculation of the market prices:

$$p^j(t) = \frac{D^j}{H^j(t)} \qquad (3)$$

with: $H^j(t) = \sum_{i=0}^{N} h_i^j(t)$ (4)

Calculation of the taxes or incentive-payments (o.Ag. = Other agrarian production, Be. = Bioenergy, Fo. = Forest):

$$\text{Var I: } T_i^j(t) = \begin{array}{cccc} j(t)/j(t+1) & o.Ag. & Be. & Fo. \\ o.Ag. & 0 & 0 & 0 \\ Be. & 0 & 0 & 0 \\ Fo. & \tau \cdot cs_i(a) & \tau \cdot cs_i(a) & 0 \end{array} \qquad (5)$$

$$\text{Var II: } T_i^j(t) = \begin{array}{cccc} j(t)/j(t+1) & o.Ag. & Be. & Fo. \\ o.Ag. & 0 & 0 & -\tau \cdot cs_i(a) \\ Be. & 0 & 0 & -\tau \cdot cs_i(a) \\ Fo. & 0 & 0 & -\tau \cdot cs_i(a) \end{array} \qquad (6)$$

$$\text{Var III: } T_i^j(t) = \begin{array}{cccc} j(t)/j(t+1) & o.Ag. & Be. & Fo. \\ o.Ag. & 0 & 0 & -\tau \cdot cs_i(a) \\ Be. & 0 & 0 & -\tau \cdot cs_i(a) \\ Fo. & \tau \cdot cs_i(a) & \tau \cdot cs_i(a) & -\tau \cdot cs_i(a) \end{array} \qquad (7)$$

Calculation of the carbon stock of a grid-cell:

$$cs_i(a+1) = cs_i(a) + \psi cs_i(a)(1 - \frac{cs_i(a)}{K}) \quad (8)$$

Calculation of the Carbon-dioxide – equivalent (CDE) emissions from the grid:

$$E(t) = \sum_{i=0}^{N} e_i(t) \quad (9)$$

with:

$$e_i(t) = cb + \Delta cs_i + \varepsilon_{jL} \quad (10)$$

3. RESULTS

3.1 Effects of fostered bioenergy production

In a first step, we assess the land use dynamics under fostered bioenergy production without additional instruments of climate policy. The right column in Figure 2 shows the functional response of the atmospheric carbon-stock C_{AT} to an increasing demand for energy crops D1. It can be seen that different shapes of the response curves occur, depending on the ecological or economic site-conditions considered. We grouped the shapes into three patterns. The classification was done in order to distinguish situations where fostered bioenergy production actually meets its goal and contributes to climate mitigation (decline in C_{AT} with D1, pattern I), even worsens the situation (increase in C_{AT} with D1, pattern III) or shows a trade-off behavior with worsening up to a critical D1-value and improvement only above it (pattern II). All increases result from emissions for crop-production and the destruction of the terrestrial carbon-stock caused by the conversion of land for an increased cultivation of energy plants or other crops. All declines are due to the fact that energy crops have a better climate balance than the other agrarian commodities.

3.2 Influence of ecological and economic site-conditions

In order to understand how the economic and ecological site-conditions influence the effect of an increasing demand for energy crops on the atmospheric carbon-stock C_{AT}, we tested for the robustness of the patterns depending on: the maximum carbon sequestration rate of the vegetation, the climate advantage of energy crops over the other agrarian commodities, demand for other agricultural commodities and the agents` production costs. Figure 3 indicates that the resulting pattern is mainly determined by the economic site-conditions, while the ecological conditions have almost no effect.

Pattern I is observed at economic conditions that are favorable for agricultural production (high demand for agricultural commodities, low production costs). Thus there are no cells covered by forest left when bioenergy is introduced. Cultivation of energy crops replaces cultivation of other agricultural commodities which leads to fewer emissions (because energy crops substitute fossil fuels).

Pattern II can be observed when the economic conditions allow for agricultural production but there are still areas that are not used for agricultural production. When there is a new market for energy crops their conversion becomes profitable. When they are completely converted a further increase in demand for energy crops leads to climate mitigation because land that was used for other agricultural production is converted.

Pattern III is observed at the least favorable economic conditions for agricultural production when the introduction of a market for energy crops leads mostly to the conversion of cells that had not been used for agriculture. While the occurrence of the patterns depends on economic conditions, it is also a function of the amount of fossil fuels that bioenergy can substitute (ε_{1L}, see Fig. 2, right column). For very high values of ε_{1L} the carbon emissions from land use change are compensated during the simulation period.

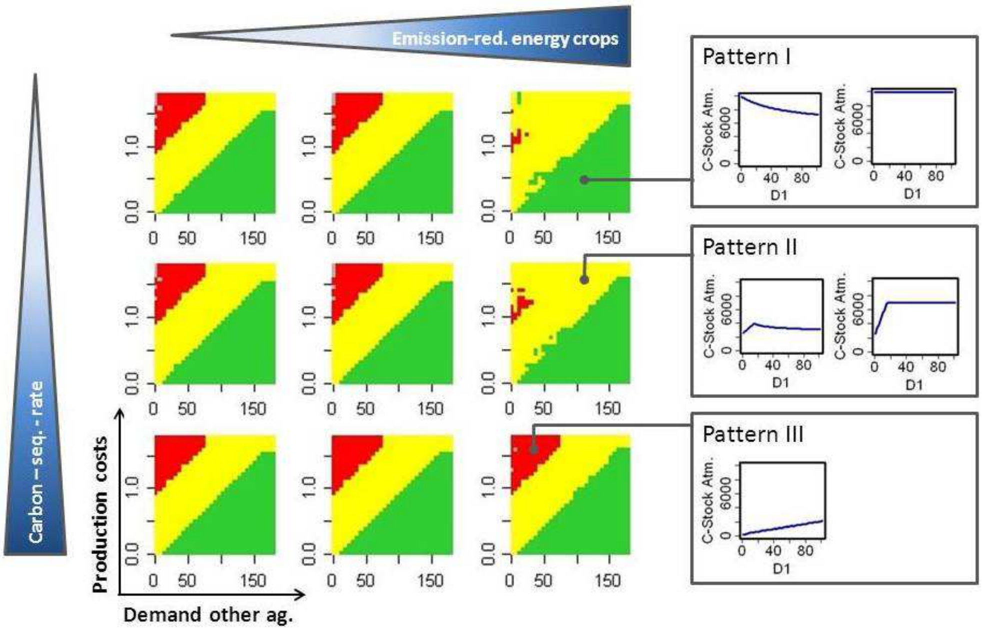

Figure 2: Robustness of the patterns of change in atmospheric carbon stock when bioenergy is introduced. The figure shows which pattern can be observed for which parameter combinations 50 timesteps after the introduction of a market for energy crops.

3.3 Climate mitigation by policy instruments that aim at the preservation of carbon stocks

In order to analyze the interplay between fostered bioenergy and REDD+ instruments we conducted simulations where we applied the three REDD+-like instruments under consideration to parameter combinations that lead to pattern I or II.

Figure 4 shows the performance of the three instruments for an economic situation where fostered bioenergy improves the climate situation (pattern I). It can be seen that the policy instruments differ in their performance: The tax on the destruction of carbon stocks has no effect as there are no carbon stocks left in the region. The situation is different for an incentive payment for establishing the terrestrial carbon-stock. There is a certain critical demand for energy crops D1 below which the payment actually leads to an improvement (reduced C_{AT}), while above the instrument loses its impact. The results also show that higher carbon sequestration rates enhance the performance of the incentive payment. In an economic situation where fostered bioenergy leads to a trade-off response of the atmospheric carbon-stock (pattern II), the picture is completely different. In contrast to the preceding case: (a) the tax on the destruction of the terrestrial carbon-stock shows an effect, that is insensitive to increasing demands for energy crops and to the carbon sequestration rates; (b) the performance of the incentive payment (Var II) for the conservation of carbon-stocks is sensitive to both site-conditions. Its` effectiveness decreases when the demand for energy crops is high. The incentive payment does not become more effective when it is combined with a tax. Further studies showed that the reason is that the incentive not to deforest is higher than the price incentive from the markets for most of the agents. There are some agents that reconvert their cell from forest to agricultural use after choosing the incentive payment in the timestep before. However they are so few that there is no effect on the macro-level.

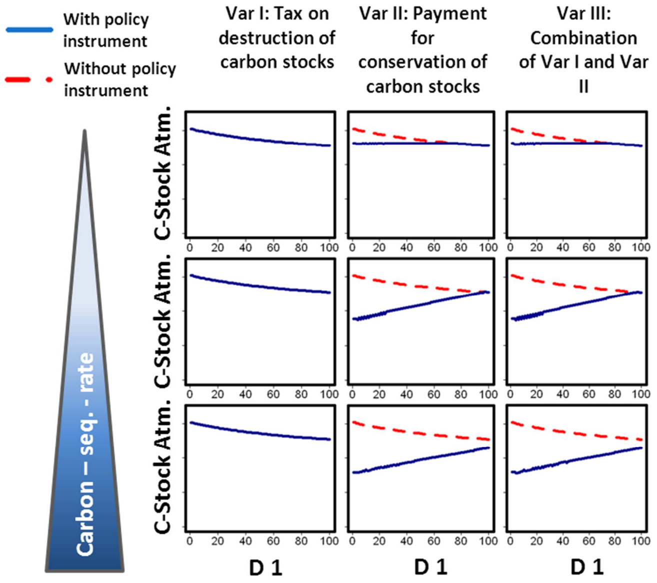

Figure 3. Change in atmospheric carbon stock C_{AT} under increasing demand for energy crops D1 for the three REDD+-like policy instruments under consideration. Shown are simulation results 50 timesteps after the introduction of a market for energy crops and of the policy instrument for economic framework conditions that lead to pattern I.

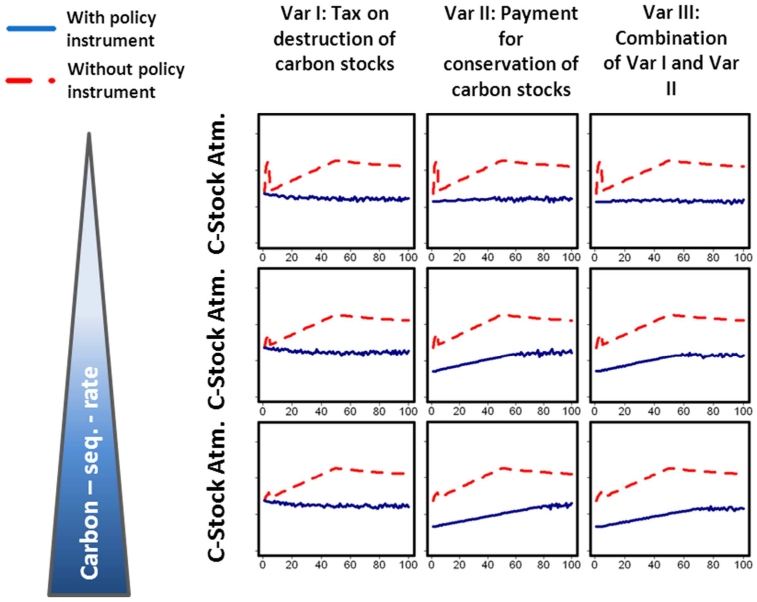

Figure 4. Change in atmospheric carbon stock C_{AT} under increasing demand for energy crops D1 for the three REDD+-like policy instruments under consideration.

Shown are simulation results 50 timesteps after the introduction of a market for energy crops and of the policy instrument for economic framework conditions that lead to pattern II.

4. CONCLUSIONS AND RECOMMENDATIONS

We presented results of an agent-based model that is designed to study the influence of different instruments of climate policy on the carbon balances of a region. We showed that economic site-conditions like the cost functions of the agro-producers and the demand for agricultural commodities influence the response of the carbon balances to fostering the production of bioenergy. We also showed that these site-conditions have a strong effect on the performance of policy instruments such as REDD+ that are designed to maintain terrestrial carbon stocks. This leads to the conclusion that information about the economic conditions in the region where policy instruments are applied is crucial to decrease the risk of unwanted side effects or inefficient governance.

We also showed that the policy instruments differ in their performance and that an incentive payment can be effective on its own when the incentive set by it is strong enough.

The results also show the potential of agent-based models of land use change for improved design of instruments for climate policy: (a) Alternative policy instruments can be assessed and compared regarding their performance. (b) Combined effects can be explored providing insight into possible pitfalls (side-effects, neutralization) and chances (synergy) of combining instruments. (c) It can be tested to what extent the results are sensitive to (ecological and economic) site-conditions, applicable to a broad range of situations or require regional adaptation.

REFERENCES

Achten, A.U., Verchot, L.V., Implications of biodiesel-induced land-use changes for CO_2 emissions: case studies in tropical america, africa, and southeast asia, *Ecology and Society*, 16(4), 14, 2011.

Berger, T., Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis, *Agricultural Economics, 25*, 245-260, 2000.

Butler, R.A., Koh, L.P., Ghazoul, J., REDD in the red: palm oil could undermine carbon payment schemes. *Conservation letters*, 2(2), 67 – 73, 2009.

Fargione, J., Hill, J., Tilman, D., Polasky, S. and P. Hawthorne, Land clearing and the biofuel carbon debt, *Science*, 319, 1235-1238, 2008.

Killeen, T.J., Schroth, G., Turner W., Harvey, C.A., Steininger, M.K., Dragisic, C. and Mittermeier R.A., Stabilizing the agricultural frontier: Leveraging REDD with biofuels for sustainable development, *Biomass and Bioenergy*, 35(12), 4815-4823, 2011.

Parker, D., Manson, S., Janssen, M., Hoffmann, M. and P. Deadman, Multi-agent systems for the simulation of land-use and land-cover change: A review, *Annals of the Association of American Geographers*, 93, 314-337, 2003.

Persson, M.U., Conserve or convert? Pan-tropical modeling of REDD–bioenergy competition, *Biological Conservation*, 146 (1), 81-88, 2012.