Spatial Projections of Participatory System Dynamics Modeling Outcomes: Exploring Oil Palm and REDD consequences for Local Livelihoods in Papua, Indonesia

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Abstract: This paper reports on combining the system dynamics software STELLA with the spatial simulation software GEOMOD (IDRISI) in order to visualize simulated forest cover changes produced by STELLA on maps. A socio-ecological model has been built in STELLA for Kaimana district including spatial and many non-spatial components. The model is built in a participatory manner with district officials and non-governmental organization personnel. We used it to explore environmental and social impacts of large scale plantation investments or payments for Reducing Emissions from Deforestation and Forest Degradation (REDD). We focused on the socio-economic consequences district level decisions would have for local livelihoods. The simulated outcomes are fed into a strategic discussion aiming to better inform the decision making process in Kaimana. We report on advantages and shortcomings of combining the two simulation programs and give an overview of the conservation and development outcomes under each of the scenarios explored for the Kaimana district.

Keywords: Landscape modeling; Participatory modeling; System dynamics; STELLA; GEOMOD; IDRISI; REDD; Kaimana

Introduction

Participatory modeling is the act of building a model with a group of non-modelers under the guidance of a model expert facilitator (Van den Belt et al. 2006). In various landscapes this method has been applied in order to exchange knowledge between different stakeholders, increase understanding of landscape dynamics, explore scenarios, visualize trade-offs between conservation and development outcomes and create a shared vision to achieve change in the desired direction (Beall & Zeoli 2008; Sandker et al. 2009; Sandker et al. 2010). This form of modeling seeks to envision alternative futures rather than extrapolate past trends (e.g. Sandker et al. 2007), a key criticism of Costanza (2000) on current futures modeling practices. Participatory modeling seeks to balance simplicity with accuracy: the model doesn't give new insights if it is either too simple or too complex (Sandker et al. 2010). A constraint of the system dynamics software STELLA, used to build the participatory models in the mentioned studies of Sandker et al, is that it's not spatially explicit (even though it simulates land-cover change). Simulation outcomes are therefore presented in graphs or tables, not in the form of maps. Maps and spatial representations are strong tools to envision and discuss preferred future landscape scenarios (Costanza & Voinov 2004), which is why we explore the presentation of participatory STELLA modeling land-use simulation results as maps in a simple way.

Spatial models are often highly complex, limiting participation of non-modelers and demanding a large amount of time investment in its creation. Many (spatial) model projections of future (land-cover) changes focus on extrapolating past trends (Costanza 2000), which might give accurate predictions of land-use changes in many developed country landscapes but wouldn't do so in the situation of many forest landscapes in developing countries at the verge of transition. Sayer (2007) claims changes in landscapes are generally not orderly or predictable, something which stakeholders with landscape scale objectives should take into account.

Examples exist of future projections obtained in a participatory way but producing purely spatial simulation outcomes (Castella et al. 2005; Hulse et al. 2004; Nelson et al. 2009). An advantage of participatory system dynamics modeling over spatial modeling is the simulation of many non-spatial elements fundamental to understanding outcomes in a landscape, like household income and even less tangible features like corruption (e.g. Sandker et al. 2009). This allows participatory modeling to extend deeper into the socio-political context of decision making.

A spatial dimension is added to system dynamics modeling in the software SIMILE (Muetzelfeldt & Massheder 2003), though this seems to be either simple, for theoretical learning of a single feature displayed on square plots, or highly complex and time consuming thus allowing little participation (Legg 2003; Vanclay et al. 2003). Costanza & Maxwell (1991) combined STELLA system dynamics modeling with Geographic Information Systems (GIS), each stock in STELLA representing one grid cell on the map. This forms the basis of an integrated environment for high performance spatial modeling called SME (Spatial Modeling Environment) (Costanza & Voinov 2004). This again is highly complex and time consuming, e.g. to run the model eight parallel processors were needed. Furthermore, extensive information is needed to feed into the model. One would have to question whether the spatial representation of the explored scenarios would be worth the large time investment and whether we have enough spatial data for such a model to make sense. We opted to explore a much simpler and faster visual representation of the scenarios by combining the model platforms STELLA and GEOMOD (IDRISI).

We explore the spatial presentation of STELLA land-use simulation results for the district Kaimana in Papua, Indonesia. Papua is a location where the future will most likely bring radical changes, nothing like the landscape has experienced in the last decades, and visioning future land-cover changes in this situation is all but an extrapolation of past forest conversion trends. The local policy makers are faced with options which would have major consequences for (the spatial aspect of) the landscape. With participatory modeling we explored the consequences of major oil palm investments and payments for Reducing Emissions from Forest Degradation and Deforestation (REDD) and their consequences for forest dependant livelihoods and forest cover in Kaimana, Papua.

1. Methods

1.1. Kaimana district, livelihoods and land-use history

The Kaimana district is located in Papua (Figure 1), East-Indonesia, sharing a border to the East with Papua New Guinea. Kaimana district extends over 17,298 km^2, and is sparsely populated (2.4 people/km^2) with a high concentration of people (50% of the total population) in and around the district capital Kaimana Town. There are few roads in the district and the main transport means for the rural population consists of canoes, using the vast river network or the sea. Almost all villages are located on the river shores. The local rural population is largely dependant on the forest, followed by small scale agriculture and fishing (Table 1). They use the forest for hunting, to collect non-timber forest products (NTFPs) and some villages are involved in community logging. All villages have forest gardens (often abandoned agriculture plots)

where they grow certain NTFPs like nutmeg (Shepherd 2009). Forest re-growth on the agricultural plots is very important to restore soil fertility in the absence of fertilizers and plots are only productive for about two years (Shepherd 2009). We use mean subsistence and cash income of the local rural population as indicators of the consequences of a REDD policy or oil palm investments in the district on forest dependant livelihoods.
Kaimana district is currently for ~95% covered with forest (Table 1). There are currently six logging concessions with a license. The logging activities result in the conversion of primary into secondary forest, not in forest clearing. We consider primary logged-over forest as secondary forest.

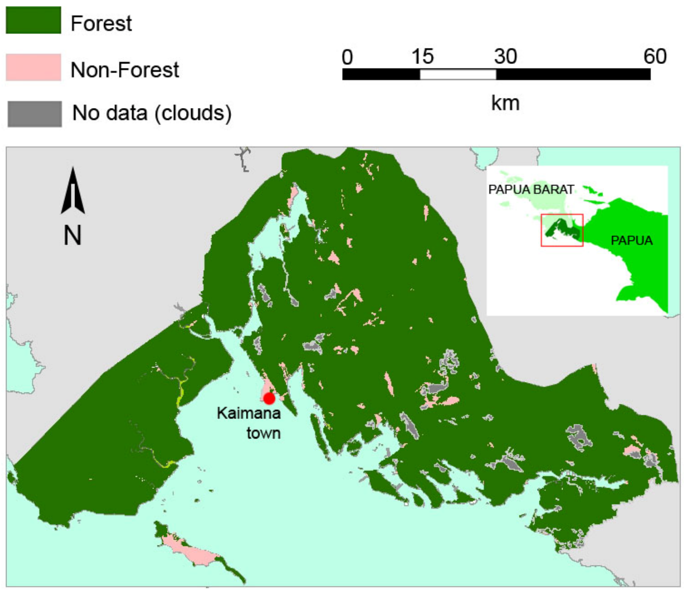

Figure 1. Forest cover of Kaimana district in 2005

Table 1. The model sectors with a summary of the information in each sector

Model sector	Information	Source
Land-use	Total district area Kaimana= 17,298 km^2 (100%) Administrative classification (indicating use destination): Other land uses (APL)= 900 km^2 (5%) Conversion forest (HPK)= 2,844 km^2 (16%) Production forest (HP)= 3,106 km^2 (18%) Limited production forest (HPT)= 5,120 km^2 (30%) Protected area = 5,273 km^2 (30%) Unclasified = 55 km^2 (<1%)	Forestry Master Plan, 2008
	Total districts' secondary forest in 2010= ~4,050km^2 Total districts' primary forest in 2010= ~12,398 km^2 Actual deforested area= ~850 km^2	Forestry Master Plan, 2008 ; compared with data Kelompok Pemangku Hutan Papua Barat Kaimana
	APL forest conversion for small scale agriculture= current area + new local households (hh)*1ha + number of unemployed migrants hh*1ha After 2 years agriculture land becomes fallow After 5 years fallow land becomes secondary forest	Expert estimation in line with historic deforestation trend
	Total industrial timber production Kaimana district = ~640,000 m^3/year	Forestry Master Plan 2008
	Timber extraction= 32 m^3/ha Annual conversion of primary to secondary forest= ~200km^2	Expert estimation based on historic data
	Parts of APL, HPK, HP and HPT are converted to oil palm and HTI depending on the scenario, part of APL is converted to forest garden	See scenario description
Population and employment	Total population Kaimana district 2008= 41,660 people	Kaimana Statistics Centre 2008
	49% of the population is urban (of which 55% is local, the rest migrant) 51% of the population is rural (of which 90% is local, the rest migrant)	Combination of expert estimate and Kaimana Statistics Centre 2008

	Birth rate= 1-4% (lowest for urban migrant population, highest for rural local population) Death rate= 1% Immigration rate= 2% (of migrant population)	Extrapolation of population growth 2007 – 2008 from Kaimana Statistics Centre 2008, modified with expert judgment
	Immigration provoked by jobs= new jobs to migrants*1.5 New jobs= new jobs in IPK, oil palm and HTI Of new jobs, only 5% can go to local population Maximum jobs local population= %age people of working age and gender * %age skilled local working age people * total local population %age people of working age and gender= 20% %age skilled local working age people= 20% now and increasing to 80% in 20 years from now (scenario 1) 20% now and increasing to 50% in 20 years from now (scenario 2) 10% now and increasing to 30% in 20 years from now (scenario 3)	Expert estimates
	Average annual salary (future) jobs = 10 million Rp (local) and 12 million Rp (migrant) Jobs in land clearing (IPK) = 0.48 worker/ha Jobs in oil palm (Sawit), acacia plantation (HTI) and logging (HPH)= 0.2 worker/ha	Approximations based on practices in North Sumatera and Jambi, modified with expert judgment
Rural local household income	Total mean income per capita= 4 million Rp in 2009 Rp = Indonesian Rupiah, 1US$ = 9,328 Rp (February 2010)	Expert estimate
	Of total income 45% is cash and 55% subsistence Forest products make up 43% of income, 41% of cash income in 2009 Agriculture make up 39% of income, 42% of cash income in 2009 Fisheries make up 15% of income, 11% of cash income in 2009 The remainder is made up of salaries, fees and other	Shepherd et al. 2009
	Cash from agriculture is simulated to increase linearly with the increase in jobs growing to a maximum of 85% of total agricultural income	Expert estimate

1.2. Scenarios

Papua has a history of relatively low deforestation rates. However, the district head (*bupati*) has 25-30 proposals for oil palm plantations waiting on his desk while at the same time he has been approached by international investors interested in buying carbon stored in the forest to sell on the future REDD market (pers. com. vice-bupati 2009). Discussion with district officials and non-governmental organization (NGO) personnel resulted in the identification of three scenarios they thought plausible for Kaimana:

Scenario 1) "Small is beautiful-growth with conservation": as of year two in the simulation, each year 10,000 ha are allocated to oil palm and 10,000 ha are allocated to acacia plantation. The limit for suitable oil palm area is set at 190,000 ha (rePPProt unpublished) and the limit for suitable acacia plantation area is set at 260,000 ha outside the suitable oil palm area (Ministry of Forestry, unpublished). A medium investment in NTFPs is made; each year '25ha + 0.1ha*increase local rural households' is converted to forest garden.

Scenario 2) "Building an industrial future": as of year two in the simulation, each year 20,000 ha are allocated to oil palm and 20,000 ha are allocated to acacia plantation. The limit for suitable oil palm area is set at 320,000 ha (inspired by Conservation International suitability map) and the limit for suitable acacia plantation area is assumed 260,000 ha outside the suitable oil palm area. A low investment in NTFPs is made; each year '0.1ha*increase local rural households' is converted to forest garden.

Scenario 3) "A future of forests-A focus on environmental services": as of year two in the simulation, each year 1,000 ha are allocated to oil palm and 5,000 ha to acacia plantation. We believe the introduction of plantations in Kaimana is inevitable and under the most conservative scenario the expansion is limited, not zero. A high investment in NTFPs is made; each year '50ha + 0.1ha*increase local rural households' is converted to forest garden. The conservationists' scenario could be a consequence of implementation of a REDD policy. Ideally, under such a scenario, the local population receives a share of REDD payments but given the situation of local people remotely distributed over the district and given high corruption levels in Indonesia we explore this scenario without any REDD payments received by the local population.

1.3. Participatory modeling with STELLA

Participatory modeling is the act of building a model with a group of non-model experts under guidance of a model facilitator. The objectives of participatory modeling include increasing understanding of complex dynamic systems (landscape in this study), thinking through drivers of change responsible for past and future trends of landscape aspects and promoting interdisciplinary exchange of information and visions (Sandker et al. 2009, 2010; Van den Belt 2004). Data is often lacking in landscapes such as Kaimana and information gaps are filled with data from unpublished reports or local expert estimates. The simulated outcomes are therefore of indicative value, they explore future landscape pathways rather than predict precise outcomes. However, the model is conceptualized and the simulation results are validated by, and at the same time disseminated among, local experts. The participatory model has been built using the system dynamics software STELLA (HPS 1996). This icon-based model building tool makes system dynamics modeling accessible to a wider public and is readily understood by non-model experts (Van den Belt 2004). The Kaimana model consists of three sectors, given in Table 1 together with their most important variables, equations and information sources.

1.4. Spatial projections with GEOMOD (IDRISI)

When spatially projecting with GEOMOD, the forest cover change is simulated by STELLA, while the location of change is simulated by GEOMOD. GEOMOD is a land-use change simulation model that predicts the locations of grid cells that change over time (Eastman 2009 p. 84). The simulations can occur either forward or backward in time, we only use the forward simulation.

We entered in GEOMOD a map of beginning time, the 2005 map in Figure 1 being the most recent available to us, which has been re-classified into two categories 'forest' and 'non-forest'. The beginning time is thus set to 2005; the ending time of the simulation is set to 2030, coinciding with the ending time of the STELLA simulation.

GEOMOD can use two decision rules for simulating the location of change, one rule being based on proximity, the other on suitability. We exclude the decision rule based on proximity. Its inclusion would allow only cells on the boarder of forest and non-forest to be converted. If large-scale plantations will be installed in Papua, deforestation patterns will not be anything like the district has seen in the past, current deforested patches will not influence the location of future change. The suitability map is created instantaneously in GEOMOD by entering a number of driver maps (Figure 2). The driver maps can be given different weights, we weighed elevation as highest (higher altitudes being most limiting to oil palm expansion), followed by slopes, distance from the sea and major rivers (to include transportation costs for oil palm companies) and finally the administrative limitations (categorizing national parks as less suitable). One could explore different scenarios with different weights for the administrative limitations map to explore different 'governance scenarios' where national parks are always excluded or where they can be degazetted to give way to oil palm companies. The driver maps we prepared, their weights given in GEOMOD and the resulting suitability map created by GEOMOD and used to predict the location of changing grid cells are given in Figure 2.

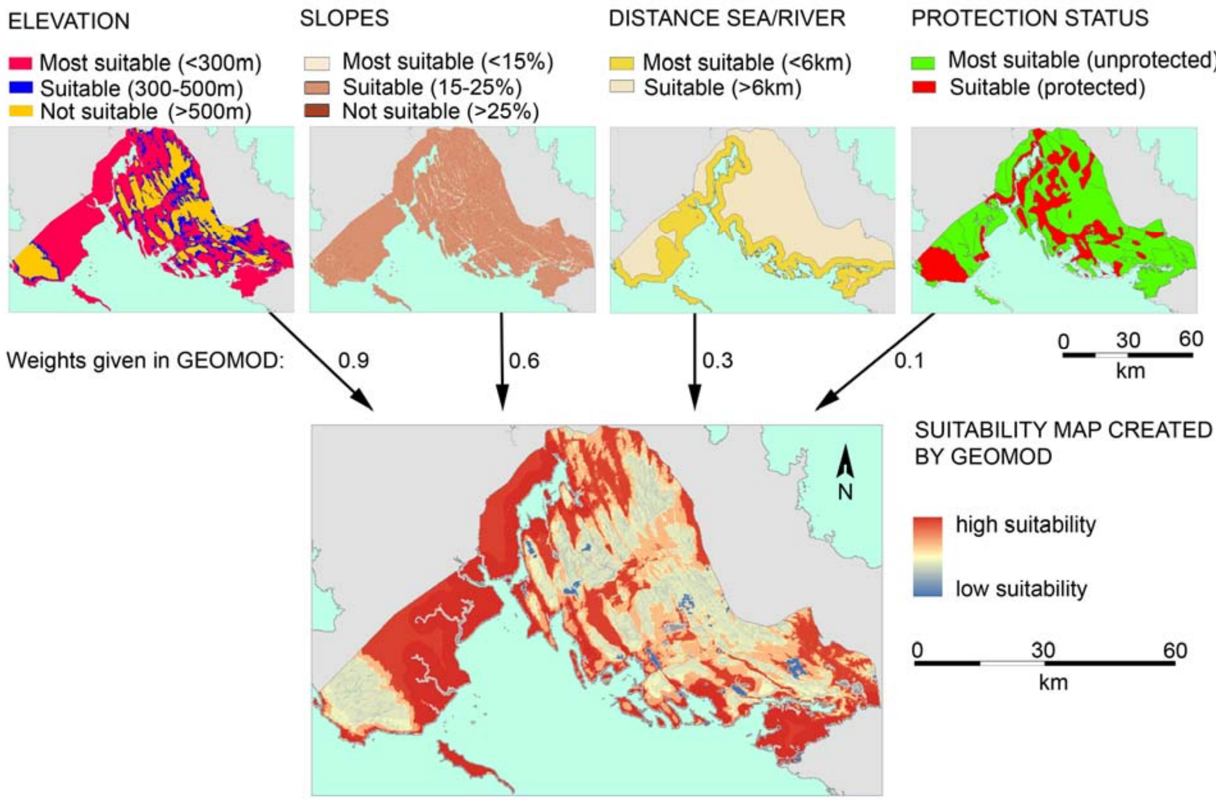

Figure 2. Driver maps entered in GEOMOD and resulting suitability map

2. Results and discussion

2.1. Land-use changes

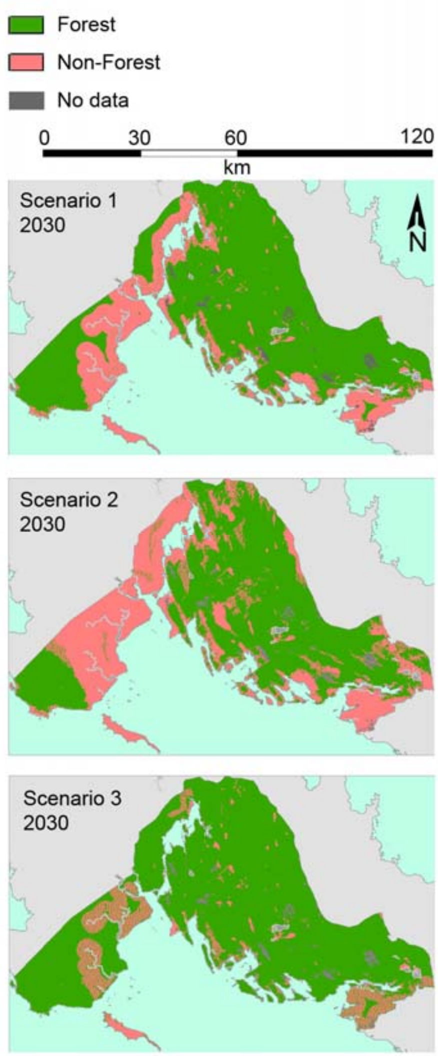

Figure 3. Maps produced by GEOMOD projecting forest cover in 2030 under the three scenarios explored

The land cover projections of the three scenarios suggest that Kaimana is at the verge of forest transition. The forest cover decreases from 16,450 km^2 in 2009 to 12,780 km^2, 10,320 km^2 and 15,350 km^2 under scenario 1, 2 and 3 respectively in year 2030 (Figure 3). These forest cover changes are the simulation result of STELLA where total forest cover is the sum of secondary and primary forest. Even under the most conservative scenario (scenario 3), the local district officials still expected 1,080 km^2 to become plantation after 20 years.

Under the industrial scenarios it is likely that a new major town will be created in the western part of the district as this is where the plantations are likely to concentrate (Figure 3). Furthermore, there is a risk of national parks being degazetted in the Western part of the district. Indeed, under both industrial scenarios (1 & 2), the national park near the sea shore in the Western part of Kaimana is not respected (Figure 2 and 3).

2.2. Population increase

At the end of the simulation, the total population of Kaimana has increased from 41,660 people in 2010 to 460,000; 740,000 and 187,000 under scenario 1, 2 and 3 respectively. Even under the most conservative scenario, the total population increases by 350%, mainly the result of people attracted to Kaimana by the jobs created in the plantations (Table 1). Under scenario 3, if one were to assume substantial REDD payments being received by the entire Kaimana population (not excluding migrants), one can imagine people being attracted to the district to share in some REDD cash. There is a possibility that such enormous invasions of the district by migrants as suggested by the scenarios would result in increased conflicts, e.g. over access to land for agriculture or over benefit sharing from the plantations and REDD investments.

2.3. Income simulations

Total per capita income and per capita cash show similar trends under the three scenarios increasing with 30-50% (Figure 4a) and 60-150% (Figure 4b) after 20 years. The income differences under the three scenarios are more marked in terms of cash. This is due to the simulated negative effects of large scale conversion of forests to oil palm causing loss in subsistence income. Negative effects simulated are pollution of the rivers and loss of forest. Water pollution causes income from fisheries to decrease with ~60% under the ‘industrial future’ scenario and with ~30% under the ‘growth with conservation’ scenario (Table 2). Forest loss causes income from forest products to decrease by 25% and 35% under the ‘growth with conservation’ and ‘industrial future’ scenarios respectively. These negative effects on subsistence income are experienced by all people, while the benefits in terms of salaried jobs are only received by some. Under all scenarios, the current mainly subsistence economy converts into a cash economy; where now cash makes up for 45% of total income, it will consist of 70, 80 and 60% after 20 years under scenario 1, 2 and 3 respectively.

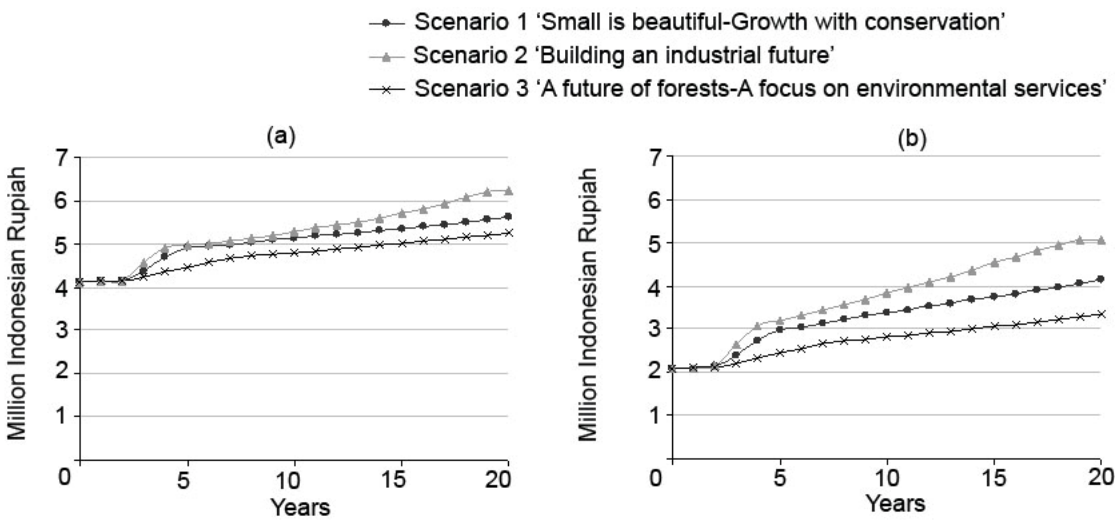

Figure 4. Simulation outcomes from STELLA of (a) total per capita income (subsistence and cash) and (b) per capita cash income for the local rural population of Kaimana

Table 2. Share of different activities (in %) of total per capita income for the local rural population of Kaimana now and at the end of the simulation under the three scenarios explored

	Agriculture	Forest	Fisheries	Salaries	Other
Now	46	36	17	1	1
Scenario 1 after 20 years	37	19	9	35	<1
Scenario 2 after 20 years	34	15	4	47	<1
Scenario 3 after 20 years	39	26	12	23	<1

Under the three scenarios, the total amount of jobs increase radically, from around 500 jobs now to 82,000; 120,000 and 25,000 jobs for scenario 1, 2 and 3 respectively after 20 years of simulation. We expected though, the capture of jobs by local people to be limited, at best circa 10% of the total jobs go to local people but the most common percentage lies between 1-5%.

Agriculture remains an important income source under all scenarios. Under scenario 1 and 2, we simulated agriculture to commercialize (Table 1) with the increased demand for food products from the huge population of salaried workers and with reduced transportation costs as a consequence of roads opening up the area. The production potential remains limited though because of low soil fertility. We assumed only the suitable land in the legally allocated area for forest conversion by local people is used for small-scale agriculture but given the enormous increase in population under the scenarios, much more forest might be converted.

2.4. REDD

The total amount of carbon prevented from being emitted after 20 years under scenario 3 is 46 million ton C when assuming a baseline based on carbon emissions under scenario 1 or 89 million ton C assuming a baseline based on carbon emissions under scenario 2. If we were to approximate a payment based on these carbon quantities, assuming a price of 150,000 Rp (16 US$)/ton CO_2 and 5% of the total REDD pay being equally captured by the local population, the annual per capita REDD pay would amount 1.5-2.9 million Rp the first year, going down to 0.3-0.6 million Rp after 20 years due to the growing population the REDD pay is shared among. Such payments would provide local people with a significant amount of cash.

Conclusion

REDD potential in Kaimana

A scenario where REDD policies would result in less conversion of forest into large scale plantations in Kaimana would avoid negative consequences from such large scale plantation invasion for the strongly forest-dependant local rural population though they would loose out on some extra cash. If local people would also receive a share of the REDD payments they would be economically better off than under the industrial growth scenarios (1 & 2), with higher incomes and comparable cash inflow. Whether such payments would reach all remote villages is doubtful, but these remote villages are at the same time less likely to benefit from jobs and more likely to suffer negatively from consequences of large scale plantations.

Combining participatory system dynamics modeling with GIS simulation

GEOMOD proved relatively simple to handle and manipulate. One can change the selection of driver maps and their weight creating different suitability maps and running different simulations in less than 10 minutes, as long as these input driver maps are prepared beforehand. This preparation was more complicated and time consuming though, since the maps had to be converted into a format which could be read and understood by IDRISI. This proved to be time consuming for a spatial software expert without specific knowledge of IDRISI. A constraint of the projection is formed by the limitation of only two land-use types. Distinguishing between large scale plantation and small-scale agriculture, and between primary and secondary forest would probably have enriched the strategic discussion on Kaimana's future more.

Within the constraint of avoiding much complexity to keep the possibility of modeling in a participatory way, the combination of the GEOMOD (IDRISI) and STELLA model platforms proved promising. GEOMOD has provided a spatial dimension to the participatory model built in STELLA, moving the strategic use of the methodology a step forward in visualizing future landscape scenarios.

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