18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009
http://mssanz.org.au/modsim09

Simulating impacts of energy prices on poverty in East Kalimantan, Indonesia

A Smajgl[a] **and G D Carlin**[b]

a Alexander Smajgl, CSIRO Sustainable Ecosystems, Townsville
b Geoffrey Carlin, CSIRO Land and Water, Brisbane
Email: alex.smajgl@csiro.au

Abstract

Adaptation dynamics of communities to environmental change, such as rainfall, forest stocks, fish stocks and flooding, have a multitude of consequences for livelihood choices, poverty and natural resource use. Emerging properties of such household level behaviour are analysed in the context of energy related policy changes in an agent-based model implemented in East Kalimantan, Indonesia. The underlying hypothesis is that complex systems modelling can help decision makers to better understand the responses of a socio-ecological system to macro-policy changes, for example fuel subsidy reductions.

The participatory model development process revealed that many decision makers implied linear responses of poverty indicators to policy interventions ("if we double cash payments we can double our impact on poverty"). The agent-based model offered the opportunity to consider feedbacks created by interactions in the socio-ecological system.

Model results indicate that poverty responses to changes in fuel subsidies and poverty cash payments are highly non-linear. Three important messages emerge from the model results. Firstly, petrol price reductions have a rather low impact on poverty alleviation. Secondly, diminishing marginal returns have to be expected as poverty levels do not seem to respond linearly to fuel subsidy changes. Thirdly, model results suggest that not just marginal but also absolute returns can decrease due to environmental feedbacks.

Keywords: *Agent-based modelling, Policy Assessment, Indonesia, Poverty*

1. INTRODUCTION

Macro-policy decisions aim to achieve targets that are often measured at a highly aggregated scale, such as GDP and inflation. Indonesia's macro policy aims for high levels of economic growth to achieve poverty alleviation targets. Some measures increase the pressure on natural resources, a pressure that can have an adverse effect on households that depend on these resources. The ultimate result could be increasing poverty levels.

This paper employs agent-based methodology to analyse the potential impact of macro policy decisions related to fuel subsidies. The underlying hypothesis is that such complex systems modelling can help decision makers to better understand the responses of a socio-ecological system to macro-policy changes, for example fuel subsidy reductions.

Fuel prices increased substantially as a result of the Indonesian Governments decision to reduce fuel subsidies as of 1 October 2005. Petrol prices increased by 87.5% and kerosene prices by 186%. Oil prices surged during 2007 and the first half of 2008 to levels that imposed a substantial constraint on Indonesia's budget. The Indonesian government decided to reduce fuel subsidies a second time effective from 1 June 2008, which led to an increase in petrol prices by 27.5% and of kerosene prices by 15%. In order to reduce the impact on poverty, each poor household received a quarterly direct cash payment of IDR 300,000 (~A$38). World oil prices have decreased since 3 July 2008. This triggered discussions on reducing fuel prices. Three options have been discussed by the Indonesian Government: a reduction of the petrol price per litre by IDR 500, by IDR 1,000, and by IDR 1,500.

In participation with the Government of Indonesia an agent-based model was developed to improve the understanding of how some regions in Indonesia will respond to macro policy changes such as the ones outlined above. This paper describes important aspects of model design for East Kalimantan. For further model results and technical details see Smajgl *et al.* (2009) and for pseudo code see Smajgl & Carlin (2009) (http://www.csiro.au/science/IndonesianPathways.html). Then simulation results are presented. We are not aiming for precision but attempt to reveal main causal relationships given such a complex system. Results should be understood as relative impacts of levers, such as fuel subsidies, on indicators, such as poverty, and not as point predictions. Important to add is that all these results are only simulated for East Kalimantan and should not be interpreted as indicators for the whole of Indonesia. This paper closes with conclusions drawn from a modelling and a policy perspective.

2. AGENT-BASED DESIGN

2.1. Methodology

Agent-based models (ABMs) are computational models which contain an explicit and individual representation of the entities of the target system being modelled and of their interactions (Gilbert, 2008). Agents in the model can represent individual entities such as humans with various levels of cognitive capacity, as well as groups of individuals and non-cognitive environmental entities. As the system representation is developed from the perspective of individual entities (bottom-up approach) agent-based modelling allows for the analysis of "evolving systems of autonomous interacting agents" (Tesfatsion, 2002). As Deadman (1999) points out, instead of defining the overall behaviour, in ABMs "this overall behaviour emerges as a result of the actions and interactions of the individual agents." This makes agent-based modelling effective in analysing complex adaptive systems (Miller & Page, 2008). In-depth descriptions of agent-based modelling can be found in Gilbert (2008).

2.2. Case study geography

This participatory model application is located in the southern half of the province of East Kalimantan (Kalimantan Timur) and comprises six districts:

- Municipality of Samarinda
- Municipality of Balikpapan
- Regency Kutai Kartanegara
- Regency Kutai Barat
- Regency Paser
- Regency Penajam Paser Utara (PPU)

The province East Kalimantan covers 211,440 km^2, and is the largest of the four provinces on Kalimantan. 81.71% of the area is land, mainly comprising production and conservation forests, oil palm and timber plantations, with the remaining 18.29% being water. The length of the provincial coast is 1,185 km and the dominating inland water body within the case study area is the Mahakam River. The Mahakam River, is approximately 920 km in length, and is the largest river in Borneo and East Kalimantan. Its catchment is divided into 5 regions. The central floodplain is known as the Middle Mahakam Area and covers about 5,000 km^2 between 116° -117° E, and 0°00' - 0°30' S (Christensen, 1992; MacKinnon, Hatta, Halim, & Mangalik, 1996). This area contains the three largest lakes of the region allowing for substantial fishing: Danau Jempang, Danau Melintang and Danau Semayang.

Situated in the wet tropics, temperatures in the case study region are very constant throughout the year and range between 25°C in some inland areas and 35°C in the lower areas. Rainfall ranges between 1500 and 4500 mm per year with higher rainfall during November to April due to the northwest monsoon (MacKinnon et al., 1996). The rainfall in the Middle Mahakam area varies between 1900 and 2500 mm. The coastal area of East Kalimantan is known to be drier than the rest of Borneo (Toma, Marjenah, & Hastaniah, 2000).

2.3. Model design

Agent-based modelling becomes an effective methodology for this project, as individual decision making has to be simulated in a dynamic socio-ecological environment. The SimPaSI (Simulating Pathways to Sustainability in Indonesia) model defines individuals as cognitive agents with a range of decision making points throughout the year. Each individual is a member of a household and each household has a home village. Based on GIS data defining administrative boundaries, the districts (Kabupaten) are created as entities as are the subdistricts (Kecamatan) and villages (Desa). Then population data is applied in order to map the realistic number of individuals into each village. Based on further demographic data these individuals are grouped into households. Census data on income of households below the poverty line is utilised, and income is accordingly distributed to create the realistic poverty indicators for each village. Within this step survey data is used to assign a type of livelihood to each individual. Then, based on interview data, typologies are assigned, which assist in the behavioural response to scenarios. This means a survey and an interview were conducted as explained below to cover critical data needs for behavioural responses of cognitive agents within each of the scenarios.

The survey involved 3,000 households across the region. Three categories of questions were asked, (a) household characteristics (e.g. number of members, income, ethnic group), (b) livelihood, and (c) values for natural resources across eight dimensions (“resource important to household as source of income, nutrition, health, spiritual values, recreational values…”). The survey revealed fish, honey, dolphins, hornbills, trees, fruit trees, rubber and rattan as the most dominant items. The variables representing these natural resources were then implemented in the agent-based model and ecological response functions were developed based on best data available.

The survey allowed also the identification of 19 household types based on their characteristics, current livelihood strategy and their values. The assumption made was that all households doing the same thing for the same reason would respond in the same way to the same change (Trébuil, Kam, TurkelBoom, & Shinawatra, 1997; Valbuena, Verburg, & Bregt, 2008). Based on the typologies 540 in-depth interviews were conducted with households that were thought to be core representatives for each of the household clusters and behavioural response rules were identified for each of the policy scenarios:

- fuel price increase
- kerosene price increase
- electricity price increase
- depletion of forest stocks
- depletion of fish stocks
- job opportunities in the coal mining industry
- job opportunities in logging companies
- job opportunities on oil palm plantations

The data on behavioural responses provides the percentage of households in each typology that reduce harvest of natural resources by different percentages. This defines the direct changes for environmental entities and alters indirectly natural resource conditions, which then create positive or negative feedback on households harvesting natural resources.

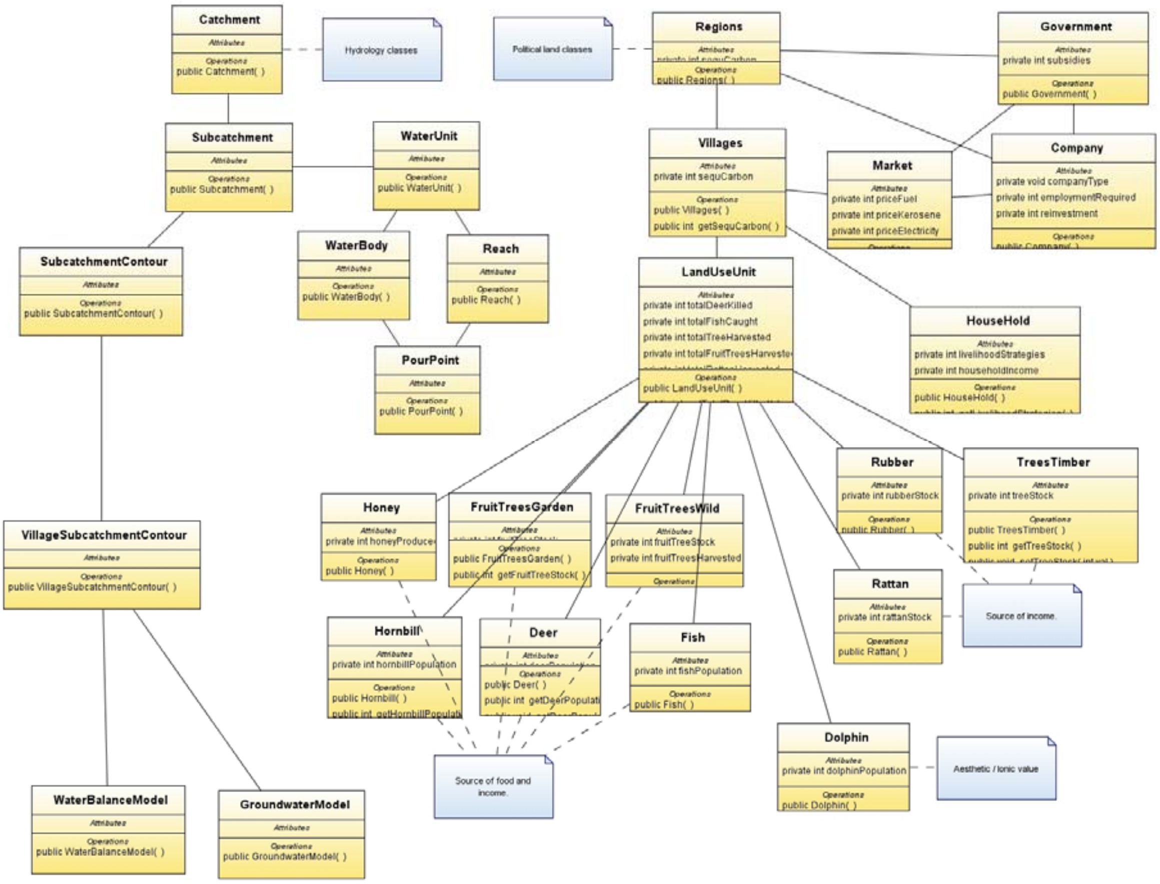

Figure 1: UML for the SimPaSI model

The UML (Unified Modelling Language) diagram in Figure 1 depicts how natural resources are linked to villages. In principle, households are entities that establish a village, which in turn, build regions. Land uses are linked to villages and validated based on official GIS data. Depending on each land use, fauna or flora entities are implemented, which contribute to the households' income. Changes in how households utilise natural resources and generate income are based on household typologies.

The landscape these agents operate in is also defined based on best available data. This includes current land use, water bodies and elevation. The weakest data in this context is the land use data as it was only available in a highly aggregated form, which did not allow for identifying different types of agriculture or types of forests. However, based on the digital elevation model for the region, an algorithm was applied to calculate the surface water and groundwater flow directions based on work by Cook and implementation by Carlin (Cook, Carlin, & Hartcher, 2007b; Cook, Carlin, & Hartcher, 2007a; Carlin et al., 2007).

In weekly time steps, agents move through the following sequence of actions and decision making points. First, depending on the livelihood, natural resources are harvested, including fish, honey, rattan, deer, and rubber (Smajgl et al. (2009).

Following this step the income is calculated for each household based on the active livelihoods for each household member. Then the income is compared with the minimum required to cover the nutritional needs of all household members. If income is insufficient, education, gender and age of members of these households are compared with available livelihoods. Livelihood availability depends on season and the labour market. If a livelihood is available (i.e. harvest is possible or labour demand exists) the household member is assigned a new livelihood (conditions regarding education and age apply) and income is updated. At the end of each week individuals that cross age thresholds between 40 and 60 years retire, which is dependant on their livelihood. For instance, for the mining sector a retiring age of between 45 and 50 is assumed and the range for logging companies is assumed to be 50 to 55 years.

At the beginning of the next time step, age and education are updated. At this stage young persons can take on work. The harvest of natural resources is again calculated, and so on.

In case a policy scenario is activated, agents read before executing their livelihood and their behavioural response, which is defined by interview data as described above. One important note is that logging and mining companies were not interviewed but were implemented with regard to their demand for labour and their logging rate. This information is based on expert knowledge and implies employment per km^2 logging/mining operation and logging rate in ha per week. Experts indicated that responses to fuel price changes are negligible. Terrain-related accessibility was reported as the factor next to the dimensions of

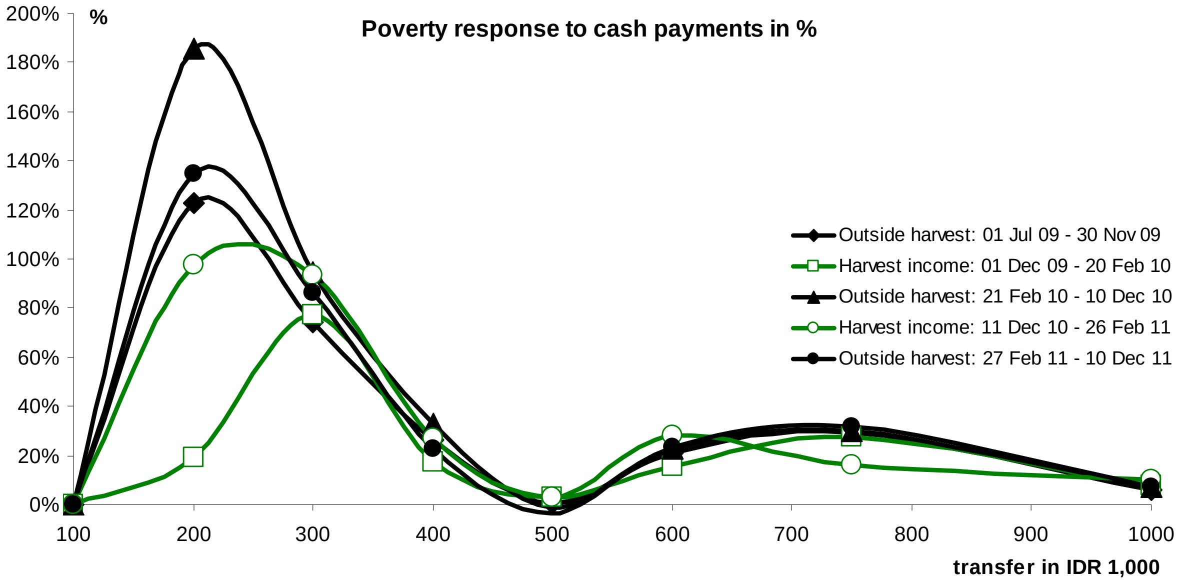

Figure 2: Marginal impact of increases in poverty cash payments

approved concessions. The concession size and location at a regency/municipality level is based on real data and was disaggregated to village level information with help of experts. These data limitations confine the scope of this model predominantly to household behaviour.

As many input parameters are uncertain and are implemented as range values, Monte Carlo simulations were conducted. Tests indicated that after about 35 runs a stable distribution was achieved (unchanging mean, max and min values). Hence 50 runs were conducted for each scenario.

3. MODEL RESULTS

3.1. Principle poverty pattern

Simulating livelihoods and household income in East Kalimantan at a daily time scale reveals a clear harvest-driven pattern. During an eight to eleven week phase starting around December, the number of households below the poverty line drops by between 35 and 40%. Seasonal income from harvesting fruit and honey increases the income of the predominantly rural households sufficiently to lift them above the poverty line of IDR 41,500 per capita and week. Therefore, some results have to be differentiated between the impacts policies have during and outside of the harvest.

3.2. Fuel price changes

In late 2008, a fuel price reduction was discussed by the Government of Indonesia as a means to reduce poverty. Price levels were about IDR 6, 000 per litre of petrol and a discussion began on how poverty could be reduced and what an effective reduction would be.

Table 1: Impact on people below poverty line

	Petrol price reduction		
	IDR500	IDR1,000	IDR1,500
Outside harvest	**2.5%** (1.8%-3.6%)	**2.9%** (1.6%-3.9%)	**2.3%** (1.2%-3.4%)
During harvest	**3.6%** (3.2%-4.2%)	**4.2%** (3.6%-5.2%)	**3.6%** (3.2%-4.6%)

The SimPaSI model was used to estimate the impact reductions of IDR 500, IDR 1,000, and IDR 1,500 would have on the number of households below the poverty line in East Kalimantan.

Table 1 depicts the impact of petrol price reductions on the number of households below the poverty line. As impacts differ results are listed for both during harvest and outside harvest.

Three important messages emerge from these results. Firstly, petrol price reductions have a rather low impact on poverty alleviation with 2.3% to 2.9% outside of harvest seasons. (During harvest the effect appears higher but in absolute terms is about the same as 36% less people are poor.) Secondly, diminishing marginal returns have to be expected. Model results suggest a 2.5% decrease in people below the poverty line due to a reduction of the petrol price by IDR 500. Doubling the public expenditure increases poverty reduction by 0.4% only. Thirdly, model results suggest that not just marginal but also absolute returns can decrease. This result emerges from natural resource-based feedback mechanisms. Reducing the fuel price further than IDR 1,000 increases the incentive for many more people to engage in livelihoods such as fishing and honey collecting. These two high value resources are suddenly shared by many more people as associated costs for driving boats and trucks decrease. Such non-linear dynamics lead to perverse poverty outcomes and suggest a reduction in petrol prices by not more than IDR 1,000.

In summary, petrol prices do not have a very high impact on poverty and the model results suggest that decision makers cannot expect linear outcomes like, ‘the higher the reduction the lower poverty’. In January 2009 it was decided to reduce the petrol price by IDR 500.

3.3. Poverty cash payment

Decisions on fuel subsidies have been linked to cash payments to poor households. This link promises less pressure on national budgets while shielding the poor. The decision from June 2008 included quarterly payments of IDR 300,000 for each poor household while fuel subsidy reduction triggered an increase of petrol prices by 27.5% and kerosene prices by 15%. Model results suggest that these three changes had a combined effect of 5.4% less poverty in East Kalimantan (Smajgl et al., 2009). While this scheme was scheduled to phase out poverty payments by July 2009, a new discussion started in early 2009 to extend these payments. Based on this discussion the model SimPaSI was used to identify the impacts of different levels of cash payments.

Scenarios simulated included quarterly payments to poor households between IDR 100,000 and IDR 1,000,000. The abscissa in Figure 2 shows the level of payment simulated in seven steps. The additional impact on poverty achieved by moving from one step to the next, is measured along the ordinate. (Poverty is again measured as the number of persons below the poverty line.) Three black lines show the average impact of each of the payments outside the harvest (2009, 2010, & 2011) while the green curves depict impacts on poverty during the harvest period (2010 & 2011).

Increasing the payment from zero to IDR 100,000 has nearly no impact. Stepping from a payment of IDR 100,000 to IDR 200,000 seems to more than double the impact on poverty. A ‘local optimum’ with highest marginal returns seems to exist between IDR 200,000 and IDR 300,000. Stepping from IDR 200,000 to IDR 300,000 seems still to deliver a similar reduction as the previous step. Adding another IDR 100,000 is aligned with diminishing marginal returns and stepping to IDR 500,000 has zero additional impact. A second local optimum seems to exist around IDR 750,000. In absolute terms, model results suggest that a poverty payment of IDR 300,000 reduces poverty payments by around 34,000 people, and a payment of IDR 400,000 or IDR 500,000 by around 44,000 people.

The marginal view indicates highest efficiency of public funds around IDR 250,000. Recently it was decided that quarterly cash payments should be continued with IDR 300,000 per poor household.

4. CONCLUSIONS

From a modelling perspective the agent-based methodology met demands of decision makers by capturing interactions between natural resources and various types of agents. Complex systems modelling can help decision makers to better understand the responses of socio-ecological systems to macro-policy changes, such as fuel subsidy reductions. The ability to disaggregate down to the village level and therefore distinguish spatial impacts of macro policy changes was an essential asset to the central government.

From a policy perspective, model results suggest that changes in fuel subsidies and poverty cash payments are likely to have non-linear responses to poverty. Some of the counter-intuitive results stimulated vivid discussions among decision makers and broadened the systems understanding considered in following discussions. In particular, feedback from natural resource use and the lack of linearity, were among the points decision makers raised in workshops that followed presentations of model results.

The results in this paper are presented solely to give an indication of the consequences for East Kalimantan. As Indonesian regions are very diverse, these results could, with some caution, apply to similar districts, for instance in other parts of Kalimantan or in Papua. But they cannot be generalised for whole Indonesia. Therefore, a series of similar models are in development for other 'representative' parts of Indonesia.

5. ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding received by AusAID, CSIRO and Profor/World Bank.

6. REFERENCES

Carlin, G. D., Cook, F. J., Cropp, R., Hartcher, M., Smajgl, A., Yu, B. et al. (2007). Using a catchment contour approach for simulating ground and surface water behaviour within agent-based modelling platforms. In *ModSim2007* Christchurch, New Zealand.

Christensen, M. S. (1992). Investigations on the Ecology and Fish Fauna of the Mahakam River in East Kalimantan (Borneo), Indonesia. *Internationale Revue der gesamten Hydrobiologie und Hydrographie, 77,* 593-608.

Cook, F. J., Carlin, G. D., & Hartcher, M. G. (2007a). *Groundwater Model for Agent Based Modelling* Brisbane: CSIRO Land and Water.

Cook, F. J., Carlin, G. D., & Hartcher, M. G. (2007b). *Water balance model for agent based modelling* Brisbane: CSIRO Land and Water.

Deadman, P. (1999). Modelling individual behaviour and group performance in an intelligent agent- based simulation of the tragedy of the commons. *Journal of Environmental Management, 56,* 159-172.

Gilbert, N. (2008). *Agent-based models*. (vols. 153) Los Angeles: SAGE Publications.

MacKinnon, K., Hatta, G., Halim, H., & Mangalik, A. (1996). *The Ecology of Kalimantan*. (vols. 3) Oxford: Oxford University Press.

Miller, J. H. & Page, S. E. (2008). *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton and Oxford: Princeton University Press.

Smajgl, A. & Carlin, G. (2009). *Simulating Pathways to Sustainability in Indonesia: Design Document - Case Study Application for East Kalimantan* Townsville: CSIRO.

Smajgl, A., Carlin, G., Pambudhi, F., Bohensky, E., House, A., Butler, J. et al. (2009). *Assessing impacts of fuel subsidy decisions on poverty and forest depletion in East Kalimantan, Indonesia: An agent-based analysis* (Rep. No. 2). CSIRO.

Tesfatsion, L. (2002). Agent-Based Computational Economics: Modelling Economies as Complex Adaptive Systems. Department of Economics, Iowa State University [On-line].

Toma, T., Marjenah, & Hastaniah (2000). Climate in Bukit Soeharto,East Kalimantan. In E.Guhardja, M. Fatawi, M. Sutisna, T. Mori, & S. Ohta (Eds.), *Rainforest Ecosystems of East Kalimantan* (pp. 13-25). London: Springer.

Trébuil, G., Kam, S. P., TurkelBoom, F., & Shinawatra, B. (1997). Systems diagnoses at field, farm and watershed levels in diversifying upland agroecosystems: towards comprehensive solutions to farmers' problems. In P.S.Teng, M. J. Kropff, H. F. M. ten Berge, J. B. Dent, F. P. Lansigan, & H. H. Van Laar (Eds.), *Applications of Systems Approaches at the Farm and Regional Levels* (pp. 99-114). The Hague: Kluwer Academic.

Valbuena, D., Verburg, P. H., & Bregt, A. K. (2008). A method to define a typology for agent-based analysis in regional land-use research. *Agriculture, Ecosystems and Environment, 128,* 27-36.