Food Security, Energy Equity, and the Global Commons:

a Computable Village Model applied to sub-Saharan Africa

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Abstract
Degradation and fragmentation of vital forest eco-systems are serious challenges for sub-Saharan Africa. It is expected that current trends of deforestation will intensify, caused by the rapid extension of biofuel production. We developed a village model to analyse the impacts of alternative resource management options on local income distribution and long-term resource use. The analysis has been at first applied to the Kakamega District of Western Kenya. Model results validate the importance of forest income for the poor. Sustainable utilisation of forest resources will not be feasible unless alternative energy systems have been broadly integrated into the village economy.

Keywords: Deforestation, Resource Management, Bioenergy, Village CGE, Value Chain Analysis, sub-Saharan Africa

Rationale and objective
Degradation and fragmentation of vital forest eco-systems are serious challenges for sub-Saharan Africa. It is expected that current trends of deforestation will intensify, mainly caused by the rapid extension of biofuel production. Today we experience a growing area of conflict between global environmental concerns and the needs for direct utilisation of natural resources by the resident population. The World Bank Study "Counting on the environment" illustrates the importance of forest environmental income for the rural poor (World Bank 2004). Besides food security, access to energy is considered to be central for poverty reduction (UN 2007). At present more than 500 million people in sub-Saharan Africa still rely on solid biomass to meet basic energy needs. In some least developed African countries traditional biomass still accounts for up to 90% of primary energy supply (IEA 2006). The unsustainable use of wood reinforced by steady population growth accelerates deforestation, resulting in soil erosion, desertification, and biodiversity loss. Furthermore, traditional energy use patterns are recognized to have negative repercussions on human health and to keep alive gender disparities. In a number of regions women must walk at least six to ten km to collect fuel wood (IISD 2005). Degradation of woodlands will further increase time to collect wood resources in the future. Energy from modern renewable sources like small hydro, solar and wind energy systems has high capital costs, and for this reason normally is inaccessible for remote poor communities. Liquid biofuels however are less-capital intensive, thus could provide a practicable alternative to modern technologies (UN 2007). In general, biofuel production from local feedstock is supported by traditional knowledge and provides communities with essential energy services and multiple valuable by-products. Even so, a reason for scepticism is bad agricultural practice, the consequences of which are loss of biodiversity, degradation of environmental services, increased food prices, and growing income disparity.
What options are available to restrain the encroachment of land used for energy production in sensible environmental areas? Is it possible to achieve the dual goal of biodiversity conservation and controlled forest extraction for supporting rural livelihoods? Biodiversity loss and conflicting uses of environmental services underline the need for a well thought-out management of natural resource use in sensitive areas, accounting for both, environmental and basic human needs. This also includes research on sustainable biomass certification (UNEP-DTIE/ROA 2007, Cramer 2007, van Dam et al. 2006), and on innovative agro-forestry systems that mimic natural ecosystems and facilitate biologically diverse production (Scherr and McNeely 2008). Actually, one focus of research is on the introduction of new mixed cropping systems for combined production of food and energy crops. *Jatropha curcas* is one of these promising energy plants supposed not to replace food crops (van Eijck and Romijn, 2008, Del Greco and Rademakers 2006, Dufey et. al. 2007).

However, research on costs and benefits is still in an experimental state, and collected data show shortcomings, especially with respect to information on seasonal labour requirements. It is often assumed that labour is in surplus in developing countries. Conversely, empirical evidence suggests that for small-scale farmers in sub-Saharan Africa family labour is more often a scarce resource showing huge seasonal peaks and bottlenecks (Spaan et al. 2004). These agronomic facts are significant for meaningful cost benefit analysis, but often neglected in assessments that are primarily based on highly aggregated data.

A village model is a useful tool for analysing differing, sometimes unreliable field data. The model system presented in the paper is based on a village social accounting matrix (SAM) that portrays the circular flow of transactions within the village economy. Village markets represent the main link between the economy and nature. The natural resource base is a key input in peasant production systems, therefor the village SAM is supplemented by environmental accounts. Model simulations illustrate repercussions of policy programs on natural resources; they show distributional effects within the village and thus point to the feasibility of policies. Derived opportunity costs indicate costs and benefits of alternative strategies. A modelling approach applicable to quantify different management options and their resulting environmental and distributional effects can support a qualified decision process.

The paper describes the basic modelling concept for investigating determinants of land use management. At first, the analysis has been applied to the Kakamega District in Western Kenya. Until today there are competing interests of forest resource use (Pascal, Tiers and Dosso 2004). At the international level, there are claims for the option and existence value of Global Commons. Besides these entitlements, the national government substantiates claims to support economic growth namely by the tourism sector. Finally, at the local level there are the interests of the local population that is heavily dependent on direct use values. We specify a value chain for local Jatropha production, and evaluate prospects for alternative employment and additional income that might reduce pressure on the forest. The model will be also applied to agro-forestry systems in Tanzania and Namibia.

Description of the current forest management

Today, significant movements from state-driven centralised forest management towards community-based management regimes can be observed (Kowero et al. 2003, FAO 2007). Experiences with common-pool resources indicate their "tragedy" if not appropriately managed. Kakamega forest has been exposed to unsustainable practices for decades resulting in continuous fragmentation of forest coverage and persistent degradation of environmental functions (Lung and Schaab 2006). The immense ecological value of the remaining forest fragments is broadly recognized today, while resource competition is persisting. Actually, the management of Kakamega forest is supervised for the most part by two institutions (Guthiga 2007). The Kenya Wildlife Service (KWS), subordinated to the Ministry of Wildlife and Tourism governs about 4400 ha. KWS applies a protectionist-oriented management strategy. Direct extraction is absolutely prohibited and only guided tourist tours are operated. In contrast, the Forest Department (FD) employs an incentive-based management strategy showing some forms of cooperation with local communities and institutions. The local population is allowed to extract firewood, thatching grass, and to graze animals on glades within the closed forest. FD has been working under the legislation of the Ministry of Environment and Natural Resources. Recently in 2007, the FD was reorganised, and today it constitutes the Kenya Forestry Service (KFS). KWS Management is supposed to bring about regeneration of indigenous forest resources and beside this positive development showing fewest illegal activities such as logging, debarking and charcoal burning (Bleher et al. 2006).

Description of the village model

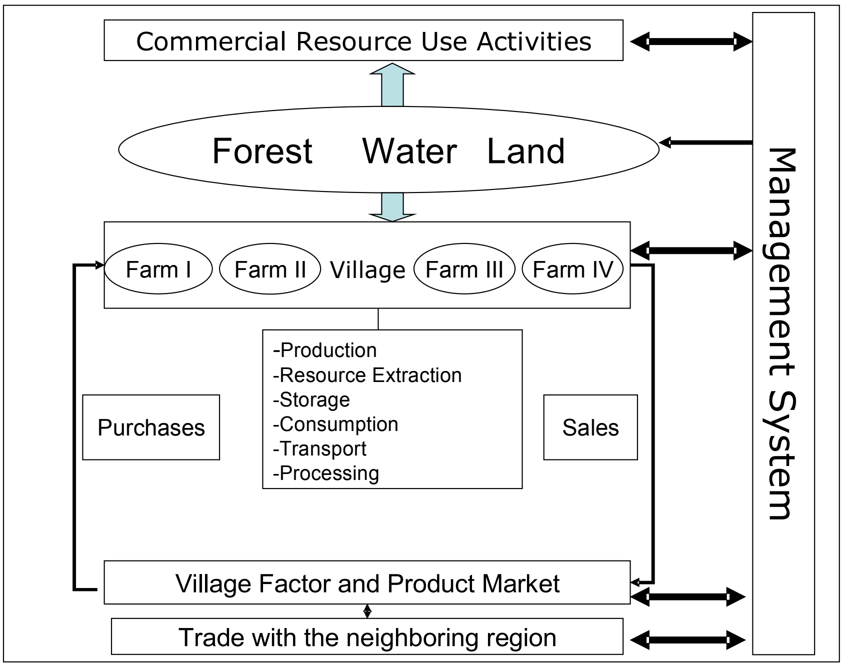
For considering competing resource uses and their dynamics, and for analysing interactions between different stakeholders, we developed a model consisting of a number of modules that represent the different users of the forest. We consider representatives that operate within a stretch of land surrounding the forest boundaries up to a distance of approximately 5 kilometres. The total population within this area is estimated at 582300 people. On average, a typical household accommodates 6 persons and cultivates one hectare of agricultural land. The total area covers about 1671 square kilometres including approximately 240 square kilometres forest land (Mueller and Mburu 2008).

The entire village model consists of six components:

1. Modules representing diverse groups of farm households
2. A commercial sector module supplying different forest products and services
3. A component depicting the local market for food and forest products
4. The management system setting constraints and policy objectives
5. A forest bio-economic module
6. Trade with neighbouring regions

Figure 1 describes the basic structure of the modelling system. Farm households and commercial sectors are linked to the forest, to the local market and to a management system (controller).

Figure 1 Structure of the Village Modelling System



Source: own figure

The core component maps representative household groups that represent the heterogeneity of farming systems discovered in the study area. We analysed several surveys performed in the Kakamega district. Survey outcomes compare well with respect to agronomic data (Börner et al. 2007, Conelly and Chaiken 2000, Titonell et al. 2005). In contrast, survey results show significant discrepancies with respect to income data, and the magnitude of forest extraction activities discovered (Kamau 2007, Dose 2007, Gibbon & Mbithi 2002, Guthiga 2007). It is one advantage of quantitative models to display the likely range of impacts that result from biased data. In case resource extraction is underestimated, cost benefit analysis will fail to appreciate the true impact a ban of direct resource use may have on rural livelihoods. Accordingly, the derived opportunity costs of alternative energy supply strategies and land uses are biased. Modelling agricultural household behaviour in marginal areas is complex

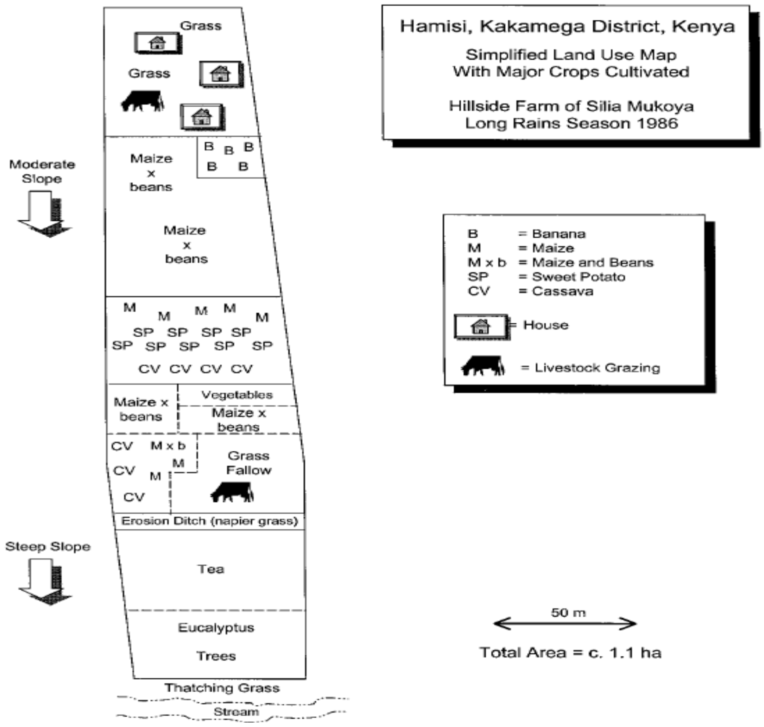
because farmers are most often not fully integrated in the market. Failure in factor and commodity markets implies that prices are distorted and cannot be used as the only guide for economic decisions. To account for market failure, various methods can be applied for calculating the true costs of factors and comodities. Labour costs for example might be approximated by considering the degree of local labour scarcity, and the grade of qualification. These kind of adjustments are usually made in economic cost benefit analysis. Alternatively, opportunity costs can be endogenously determined by specifying a more complex non-separable household model (de Janvry et al. 1991, Angelsen 1999, Taylor and Adelman 2003, Holden et al. 2005). These models abstract from the perfect market assumption and consider market disconnection due to huge transaction costs. The standard assumption of a non-separable household model is that households maximise their utility of consumption and leisure by balancing their disutility of work against their utility of consumption. In doing so, they reach their subjective household equilibrium (Nakajima 1986). We also abstract from the concept of one representative consumer. Instead, different types of rural household are considered to take into account some appearance of specialisation, and options for local trade within a village. The village model describes interactions between these different types of households. Commercial sectors may compete with farm households for scarce natural resources.
At farm level, agricultural supply is represented by a standard mathematical activity model. To be able to isolate the farm-firm component, the respective profit function π can be maximized subject to a farm type specific set of economic and environmental constraints r_n.

Equation 1

$$
\begin{aligned}
&Maximize\, \pi = f(x_n) \\
&st\; g_n(x_n) \leq r_n, \quad x_n \geq 0
\end{aligned}
$$

Production activities cover production of food, cash crops, and the *Jatropha value chain*. All activities are distinguished with respect to the timing of land preparation, planting, weeding, pruning, and harvesting, and with respect to the technology applied. Seasonal prices, the distance to the market and to the forest, and seasonal labour scarcity, and nutrition requirements determine production, storage, transport and trade in regional markets. The specification of agricultural production is based on monthly data; this is meaningful since it considers essential constraints on the optimal farm program due to labour peaks, it also keeps in mind two ore more cropping cycles per year. Important food crops are maize, beans, sweat potatoes, and cooking bananas. Major cash crops are tea, sugar cane, and sunflowers. Livestock is mainly reared for subsistence use. Indigenous dairy cattle breeds are the most important livestock. The average land holding per household in the district is a 1-2 ha, average household number is 6-7 persons, average yield of maize is 1080 kg/ha (Ministry of Agriculture Nairobi 2008). Distance to the market and availability of seasonal labour are important constraints for different farm household groups. Agriculture in many regions in sub-Saharan Africa is facing declining soil fertility. High fertilizer costs imply that the targeted area for planting reduces and soil mining increases revealing the importance of establishing alternative local energy supply systems that can offer supplementary income opportunities for rural households and may diminish stress on the environmental. We specified a combination of activities to produce *Jatropha* oil. The processes have to be integrated into to existing farming system. Figure 2 portrays a typical farm in the Kakamega district. Farmers minimize risk by operating a complex multi-species multi-cropping system that is adapted to micro-environmental variations like soil conditions and varying slopes on small parcels. It is observed in the region that more labour and more complex crop mixtures are to be found where land is particularly scarce. However, a high level of diversity does not necessarily translate into food security once population pressure becomes severe (Conelly and Chaiken 2000).

Figure 2 Simplified land use map of a typical farm in the Kakamega District



Source: Conelly and Chaiken

Principally, agricultural activities may also consider conversion of forest into agricultural land to respond to population pressure and food insecurity. In a pioneer paper, Angelsen (1999) developed a model to explain impacts of population growth, market forces and property rights on agricultural expansion and deforestation. The paper illustrates some fundamental differences of model results depending on the supposed behaviour of farm households; more precisely, assumption on market integration and property rights determine not only the degree but also the direction of agricultural expansion and deforestation. In the area our village model is applied to, agricultural expansion is de facto prohibited. For this reason we focus on forest extraction impacts and do not depict the transformation into agricultural land.

In our model, household demand is either represented by a Normalized Quadratic Expenditure System (Ryan and Wales 1999) or by a 2-stage additive Utility function (Angelsen 1999). Here, we use the additive Utility function. It includes a subsistence level of consumption $C_{subsistence}$, and an upper bound on monthly family labour availability T_{max}. The difference between maximum and actual labour represents leisure; the difference between attained household income C and minimum required income $C_{subsistence}$ defines disposable surplus income of the farm household. Income is received from activities taking place on-farm, forest extraction, and off-farm labour offered by the commercial sector. The specification of the parameters α and β determines the supposed wealth state of households. A low value of parameter α means a relative low valuation of surplus consumption. Contrary, assigning a high value to α mimics a more materialistic oriented household. The expression $(1-\alpha)$ represents the marginal utility with respect to surplus consumption $(C-C_{subsistence})$.

Equation 2 $$Max\,U(C,T) = \left(C - C_{subsistence}\right)^{\alpha} + \upsilon \cdot \left(T_{\max} - T\right)^{\beta} \quad \alpha,\beta \in (0,1), \upsilon > 0$$

In accordance with economic theory, the utility function yields positive and declining marginal utility of total consumption C and increasing marginal disutility of labour. Total differentiation yields the shadow wage Z. The shadow wage Z represents the marginal rate of substitution between consumption and labour (Equation 3). In case the household is completely disconnected from local food and labour markets, subsistence consumption determines a lower bound on food production. This implies also that Z becomes very low when the realized income level approaches the minimum subsistence level. We specify subsistence income for the farm types by using FAO minimum requirements for daily protein and energy intake per head. In addition, we consider basic energy requirements equivalent to 2 kg of firewood per person and day.

Equation 3 $$Z = -\frac{U_T}{U_C} = \frac{\upsilon \cdot \beta \cdot \left(C - C_{subsistence}\right)^{1-\alpha}}{\alpha \cdot \left(T_{\max} - T\right)^{1-\beta}}$$

Using specific functional forms has important implications for model outcomes. In the two-product case (here leisure and aggregate income), the utility function applied is flexible; the elasticity of Z with respect to an increase in productivity can take on values which are either above or below unity depending on the actually realized level of welfare. This means, different household groups may respond differently to a policy change. Including more than two independent variables, this means specifying a single-stage non-separable utility function, the Angelsen utility functional form will lose flexibility; a sophisticated form like the Normalized Quadratic Expenditure System (NQES) should be selected instead.

The commercial sector is assumed to act as a price taker in a perfect market. The commercial undertakings may encompass timber production, and tourism services. Commercial agents are assumed to maximize profits.

The forest is represented by a logistic growth model (Brander and Taylor 1997, Clark 1990). Equation 4 describes a common biological growth function considered in explaining net growth of natural resources like forest and fish stocks.

Equation 3 $$G_t = F_t \cdot r \cdot \left(1 - \frac{F_t}{k}\right)$$

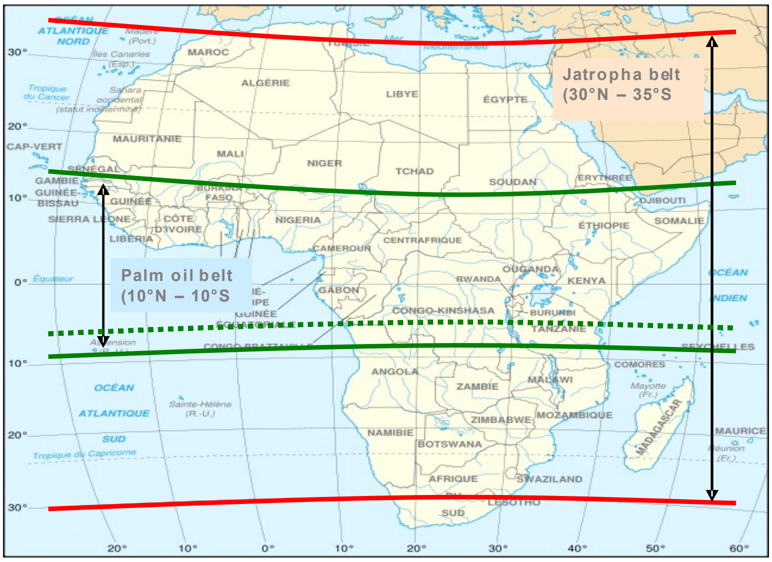
The variable F represents the state of the resource at time step t. The parameters r and k represent the intrinsic growth rate and the carrying capacity of the ecosystem respectively; thus net growth G is explained by r, k and the actual state of the resource F. In the model with a conservation management regime, it is assumed that total harvest of the resource may not exceed annual net growth G of the resource F. The controller allocates the utilisation of the resource to different agents. This is specified by a weighted benefit function. The manager may set farm household specific priorities. In case of open access, the equilibrium is defined at the point at which the resource rent becomes zero. In this specific case, no environmental benefit of resource conservation is considered by the society.

To impede further deforestation and reduce human disturbance, the remaining forest fragments of the Kakamega tropical could be completely closed as practised by the KWS. Alternatively, the management regime may operate the incentive-based strategy by charging fees for the various permitted extraction activities. The FD provides controlled access for different forest uses like grazing of animals on natural pastures, firewood extraction, and harvesting of grass. Outcomes of both strategies have been analysed by the model.

Potential of the Jatropha system for sustainable bioenergy production in remote rural communities

Apart from the promising characteristics attributed to the *Jatropha* oil-bearing bush, little systematic research has been done so far. Many uncertainties and knowledge gaps still exist referring to the question whether *Jatropha* can be cultivated and used for biofuel production in an environmental, social, and economic sustainable way (van der Zaan 2008). Actual published agronomic data show huge deviations, especially with respect to labour requirements during cultivation and harvesting. Figure 3 indicates the most appropriate climate conditions for *Jatropha growing*, ranging between 30°N and 35°S, including the Oil palm belt between 10°N and 10°S (Jongschaap et al. 2007).

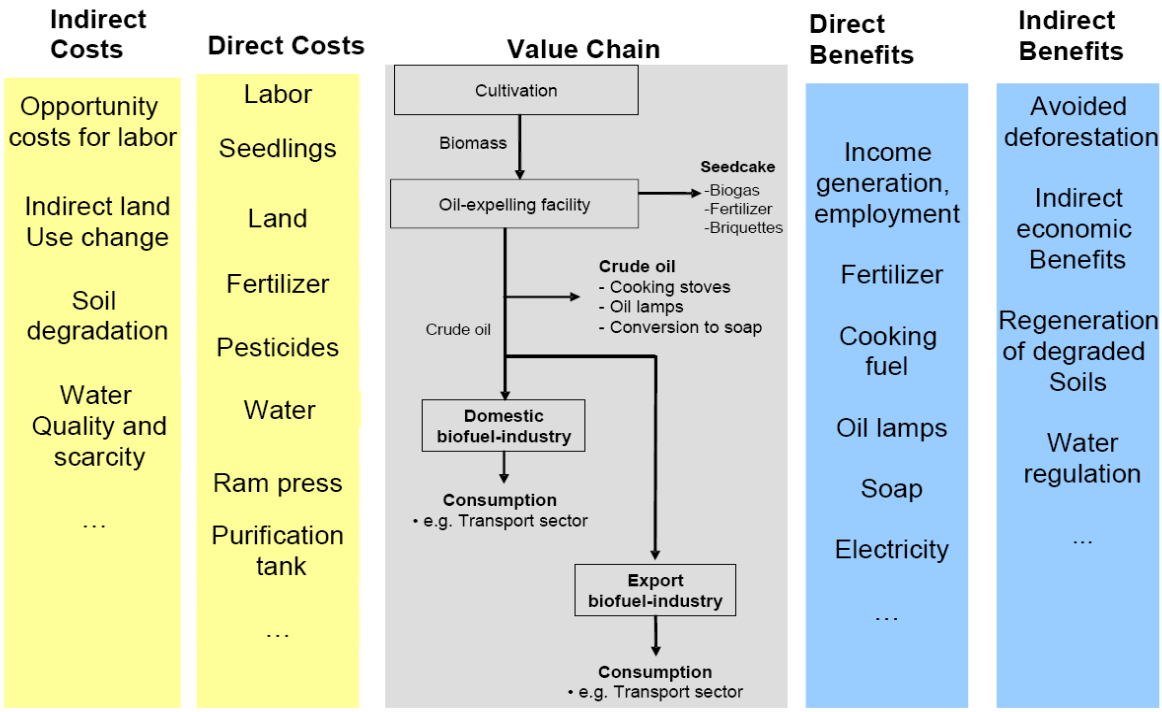
Figure 3 *Jatropha curca*s and the Palm Oil belt



Source:Adapted from Jongschaap et al. 2007

There is hardly scepticism with respect to the ecological advantages of *Jatropha*. The plant is drought resistant, well adapted to tropical and semi-arid regions. It grows on marginal lands, capable to reclaim problematic lands, and combats desertification by restoring the vegetative cover in degraded areas thus preventing erosion due to its unique root architecture of one tap-root and four laterals (Muys et al. 2007). For good yields, an average rainfall of 600-1200 mm is desirable. With annual rainfall of 1200-2000 mm, *Jatropha* production may be possible in the Kakamega district without irrigation. *Jatropha* has traditionally been used as a hedge to protect agricultural fields, and it has various medicinal and hygienic applications. The production chain additionally results in some valuable by-products such as seed cake, and fruit husks used as fertilizer or heating material. Published cost benefit calculations generally reveal acceptable gains for small-scale producers (Henning 2004). These results, however, are highly aggregated numbers, not accounting for seasonal constraints of peasant families. *Jatropha* cultivation, oil extraction, and eventual production of biodiesel occur at different scales. The UN Department of Economic and Social Affairs stresses the need to examine ways in which different scales of production and use can operate simultaneously and how they can complement and benefit from each other. Research is also needed to take into account best practices. More recently, life-cycle analysis is performed to the complete *Jatropha* chain (Prueksakorn et al. 2008). Net Energy Ratios (NER) in *Jatropha* biodiesel production yield an average NER of about 6.03; this number means energy output exceeds energy input about 6 times. The highest energy gain (NER of 11.99) could be attained if the valuable by-product, the seed cake is also used as a fuelstock. However, seed cake provides a favourable fertilizer for degraded soils substituting for expensive chemical fertilizers.
Figure 4 shows costs and benefits related to the Jatropha production chain. The chain illustrates a number of alternative uses. In our model we will focus on the options for small-scale producers. Does the value chain fit within a remote African village, and could it replace firewood collection?

Figure 4 The *Jatropha* Curcas Value Chain and related Costs and Benefits



Source: own Figure

To include the chain in the farm program, we combined various sources of data, most of it stemming from field studies in sub-Saharan Africa. Family labour spent to collect firewood depends first of all on distance to the forest. We assume 7 working hours per day and an average transported quantity of 15 kg per head lot. On average, 2 kg per head and day are consumed. Hence, a 6 person household needs about 4380 kg firewood per year. At a rate of 2 km per hour, the household most adjacent to the forest may bring home 2.3 trips a day, needing about 7 hours per month to collect the firewood for the family. This time is low compared to the literature (UNEP 2005).

Table 1: Comparison of Firewood and *Jatropha* with respect to time (hours per month)

Household type (family size) land in ha	Distance to the forest in km	Trips per day	Wood (hours per month)	Jatropha (hours per month)
H1 (4,15) 0,52	1	2,3	7,2	8,6 (7,1)
H2 (6,16) 1,17	2,5	1,6	16,1	12,8 (10,5)
H3 (4,47) 1,38	2,5	1,6	11,7	9,3 (7,6)
H4 (5,18) 1,90	5	1	21,0	10,7 (8,9)

Source: own calculations

For cooking and lighting one person in sub-Saharan Africa requires about 55 litres of plant oil per year, equivalent to 730 kg firewood (Mühlbauer et al. 1998). It is supposed that 3 kg *Jatropha* seed can be collected per hour (Henning 2004). We further take a low oil extraction rate of 20%, 1.5 hours are needed to produce one litre oil. Table 1 summarises the data to compare firewood collection and Jatropha processing with respect to labour time. Column 1 shows the average household size and land availability. Column 2 gives the distance to the forest in kilometres; trips per day are given in column 3. Column 4 and 5 display the calculated time per month allocated to firewood collection and plant oil production

respectively. The numbers indicate that group 1 has a comparative advantage to collect wood. Increasing collection time implies that *Jatropha* becomes advantageous in any case.[1]
In a second step, we evaluate land use requirements for firewood and *Jatropha* plantings. Table 2 displays the estimated wooden biomass in cubic meters per ha forest land, and the yield of *Jatropha* seed per ha.

Table 2 Comparison of Firewood and *Jatropha* with respect to land

	Indigenous Forest	Woodland and Bushland	Agro-Forestry Farmland	Jatropha*
Biomass m3/ha kg/ha*	176	18	20	3000
Sustainable use m/ha % of standing biomass	0,9 0,5	0,36 2	0,4 2	
Sustainable use kg/ha	450	180	200	
Land need per person ha	1,62	4,06	3,65	0,1

Source: own calculations based FAO Forest Outlook[2]

An average standing biomass of 176 m^3 per ha is estimated for Kenyan indigenous forests. The sustainable annual firewood extraction from these forests is supposed to be 0.9 m^3 per ha given the average density of wood is 500 kg per m^3. Applying sustainability criteria, 450 kg may be extracted per ha of indigenous forest area. Kakamega Forest extends to approximately 24000 hectares; accordingly, sustainable firewood use is about 21600 m^3 in total. This quantity is equivalent to roughly 4% of total firewood required by the local population within the 5 km radius surrounding the forest. This means, 1.62 ha indigenous forest area would be needed per head. In comparison, 0.1 ha *Jatropha* plantation land is needed to meet one person's energy needs.

The data displayed in Table 3 show selected simulation results for group 1 households. Simulation 1, 2, and 3 represent the benchmark situation, assuming differing objective functions without *Jatropha* production. The first benchmark scenario minimises family labour by assuring the minimum subsistence income required to meet minimum nutrition standards. The family allocates 527 hours to labour, and about 65% of income stems from forest resources. In the second benchmark run, pure profit maximisation is supposed; now the complete disposable time is allocated to work. Wood extraction increases significantly by 43%, accordingly, forest income grows by 11%. The third benchmark run supposes maximisation of utility. We specified the Angelsen utility function. The endogenously determined shadow wage Z compares quite well to the observed daily wage paid for unskilled agricultural labour (0.7 € per working day in 2005). The solution resembles the profit maximization run. This outcome could be explained by the extreme poverty status of group 1 households. In the first policy scenario we restrict livestock grazing on forest glades. As a result, income sharply decreases by 18 % in the utility maximization scenario. More wood is extracted and sold on local markets to compensate for income losses caused by forbidding cattle grazing. In the second policy scenario we prohibit any direct forest use. The model is not feasible under this policy program. In case, strict conservation policy is expanded to the entire area of Kakamega Forest, the poorest households represented by the group 1 cluster could not secure minimum needs.

1 Compared to other regions, firewood collection time in Kakamega is pretty low. According to the IEA report, distances in Tanzania to collect firewood are up to 11 km per day.
2 FAO Forest Outlook Studies in Africa FOSA by D. Mbugua

Table 3 Simulation results of selected scenarios for group 1 households

Household 1	Min Labour!	MAX Profit!	Max Utility!	Min Labour no grazing!	MAX profit No grazing!	Max Utility no grazing!	MAX Utility No forest use!
Subsistence income in €	665	665	665				Not feasible!!!
Surplus in €	0	151	127				
Labour in hours	527	700	673				
Leisure hours	173	0	27				
Shadow wage Z			0,86				
Wood extraction kg	11906	17035	16242	13807	16294	16749	
Share of Forest income	0,65	0,76	0,70				
% Labour				+14	0	+2	
% income				0	-8	-18	

Source: own simulation results

Table 4 Simulation results for the village

Household	H1	H2	H3	H4
Z	0,52	0,69	0,68	0,72
Surplus	0,6	412	401	6196
Labour	699	1424	687	1220
Leisure	1	54	53	0,4
Utility!	1	22	21	2500
Land in ha: own Community	0,53 0,44	1,17	1,37	1,89 8,12
Sold Labour Share	Yes 0,53	Yes 0,84	Yes 0,67	No 1,8

Source: own simulation results

Table 4 displays simulation results for *Jatropha* scenarios. We presume that all households may hire and sell labour within the village community but cannot exchange labour with outside markets, thus the model determines endogenous farm group specific shadow values of labour (Z) displayed in the first row of Table 4. Furthermore, we offer community land for free, to practise Jatropha. The constraints on minimum food production have to be maintained in this scenario, and any direct forest use is strictly forbidden. Results show that the least endowed farm households will cultivate *Jatropha* until seasonal labour allocated to subsistence production becomes binding.[3] The computed Z-values perfectly correspond to economic theory; Z is above market wage for group 4 farms, the only group hiring labour. All other households sell labour; there subjective shadow value is below the market wage. Group 2 households sell 84% of allocated labour. The most disadvantaged group 1 households have to work hard to sustain minimum nutrition needs. *Jatropha* processing is organized by Group 4 households. Nearly the total surplus provided by the new energy system is gained by this group. This result depends on the specified utility function; we postulated maximisation of joint utility without household-specific weights. However, the outcome reveals a crucial aspect actually claimed by critics of the *Jatropha* system. Without attendant distributional policy programs, social sustainability goals will not be achieved within the village community. Benefits will be relished by advantaged households, while forest conservation policy will significantly increase necessary labour time of poor families. The new supply chain might acquire a significant share of allocated labour, thus, the balance between food production and bioenergy production has to be directed by the government. There might not necessarily exist competition with respect to land use, the allocation of seasonal labour is more likely to displace food production in the region.

Conclusion

First model results validate the importance of forest income for the poorest farm household groups surrounding the forest. As a consequence of banning any forest extraction, losses of these incomes in kind would be substantial. Poor households could not survive without alternative income sources. Sustainable extraction practices will not be feasible unless alternative energy sources have been broadly integrated into the current farming system. The *Jatropha* value chains may create additional income opportunities which might also lessen pressure on the forest.

The shadow value Z computed for the wealthiest group lies above the rural market wage. This reveals the principal profitability of the *Jatropha* chain compared to jobs provided by the commercial sector at the market wage. Alternative utilization of oil and by-products, and the specification of additional bioenergy value chains still have to be integrated into the village model.

Preliminary findings suggest that forest management should account for the divergence the various farm household groups place on the values of different forest products. Payment-for-environmental-services schemes should respect household-specific opportunity costs. A part of the rent earned by common property resources should be taken for compensating disadvantaged groups and transferring capital to sustainable production alternatives.

However, model outcome reveals a crucial aspect actually claimed by critics of the *Jatropha* system: Without attendant distributional policy programs, social sustainability goals will not be achieved within the village community. Benefits will be relished by the already advantaged households, while forest conservation policy will significantly increase necessary labour time of poor families.

3 An activity model allows farmers to respond to new technologies by changing existing agricultural practice. Farmers switch to alternative production plans of cattle husbandry to reallocate scarce resources. Time consuming cattle grazing on forest glades may move to more labour saving technologies, in case more efficient energy production systems are practised, and demand additional labour input. Income opportunities via *Jatropha* processing could take pressure away from forest land. Model results illustrate this kind of prospective leakage effects.

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