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Integrating place-specific livelihood and equity outcomes into global assessments of bioenergy deployment

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Abstract
Integrated assessment models suggest that the large-scale deployment of bioenergy could contribute to ambitious climate change mitigation efforts. However, such a shift would intensify the global competition for land, with possible consequences for 1.5 billion smallholder livelihoods that these models do not consider. Maintaining and enhancing robust livelihoods upon bioenergy deployment is an equally important sustainability goal that warrants greater attention. The social implications of biofuel production are complex, varied and place-specific, difficult to model, operationalize and quantify. However, a rapidly developing body of social science literature is advancing the understanding of these interactions. In this letter we link human geography research on the interaction between biofuel crops and livelihoods in developing countries to integrated assessments on biofuels. We review case-study research focused on first-generation biofuel crops to demonstrate that food, income, land and other assets such as health are key livelihood dimensions that can be impacted by such crops and we highlight how place-specific and global dynamics influence both aggregate and distributional outcomes across these livelihood dimensions. We argue that place-specific production models and land tenure regimes mediate livelihood outcomes, which are also in turn affected by global and regional markets and their resulting equilibrium dynamics. The place-specific perspective suggests that distributional consequences are a crucial complement to aggregate outcomes; this has not been given enough weight in comprehensive assessments to date. By narrowing the gap between place-specific case studies and global models, our discussion offers a route towards integrating livelihood and equity considerations into scenarios of future bioenergy deployment, thus contributing to a key challenge in sustainability sciences.

Keywords: livelihoods, biofuels, multiple-scale analysis, food security, inequity

1. Introduction

Recent efforts to model climate change mitigation within possible future energy systems have suggested that bioenergy can play a major role. The special report on renewable energy sources (SRREN) (IPCC 2011) indicates a global potential deployment of biomass for bioenergy in the range of 100–300 EJ yr^{-1} in 2050, with possibly more than 100 EJ yr^{-1} coming from dedicated bioenergy crops—compared to about 11 EJ yr^{-1} in dedicated bioenergy crops in 2008 (Chum *et al* 2011). Similarly, the Global Energy Assessment suggests that the production of bioenergy crops may increase by a factor of 10 in 2050 (Coelho *et al* 2012). Such a high deployment of biomass for bioenergy would require a massive agricultural transformation with significant implications for both environmental and social change. The global warming effects of induced land-use change and carbon stock dynamics can negate mitigation from fuel substitution (Fargione *et al* 2008, Searchinger 2012), a result that has more recently been taken up in assessment models (Wise *et al* 2009, Creutzig *et al* 2012a). Models also consider potential widespread impacts that such an agricultural transformation would have on environmental resources, e.g. water, soil and biodiversity (Erb *et al* 2012, Gerbens-Leenes *et al* 2009, Popp *et al* 2011). But the global competition for land use (Lambin and Meyfroidt 2011) is intensified by higher demand for biofuels, and impacts not only ecological dimensions but also directly about 1.5 billion smallholders[7] and agro-pastoralists. Hence, the aforementioned studies and assessments remain deficient in two ways. First, they operationalize social impacts as economic efficiency, economic growth, and sometimes food prices, ignoring other important dimensions of human wellbeing such as change in socio-economic and health conditions. Second, the high level of spatial aggregation of the assessments makes them blind to place-specific drivers and distribution of impacts among different social groups and geographical areas within countries.

As an example of a global energy assessment, the SRREN mentions livelihoods as a relevant category (p 58 and p 90), indicating positive outcomes of bioenergy deployment for livelihoods (Chum *et al* 2011). However, it neither considers livelihood impacts as a constraint to deployment nor identifies factors shaping the interaction between bioenergy and livelihoods. The mandate of the SRREN focuses on cost-effective climate change mitigation and does not extend to evaluating goals such as poverty alleviation, other livelihood improvements, and ecological sustainability. But climate change mitigation and economic growth are ultimately not goals on their own but rather means to achieve human wellbeing. Place-specific livelihood impacts of bioenergy schemes are nuanced, differentiated and insufficiently reflected in current bioenergy assessments (German *et al* 2012, Creutzig *et al* 2012b). As a result, the livelihoods of workers, smallholder farmers and local populations, as well as distributional considerations are systematically underexplored (Corbera and Pascual 2012, Creutzig *et al* 2012b). It is these gaps—livelihoods and equity—that we seek to narrow.

In this letter, we systematically identify routes by which bioenergy deployment can influence livelihoods, influenced by global market dynamics and place-specific production models. We analyze case studies that investigate livelihood effects of cultivating the most common feedstocks for first-generation biofuels, as these constitute the vast majority of bioenergy schemes. Among these schemes, we investigate specifically those in developing countries where agriculture often remains a predominant source of livelihoods en large. We focus on the cultivation of oil palm, jatropha, soy, cassava and sugarcane. Section 2 addresses both global and local drivers and effects of biofuel deployment on livelihoods. Section 3 summarizes the livelihood effects in a conceptual figure and an example. We then discuss how these insights could be better incorporated in integrated assessments of bioenergy deployment and provide an outlook on the potential of second-generation biofuels for improving livelihoods in section 4.

2. Place-specific and global processes shape how bioenergy affects livelihoods

Livelihoods include ‘flows’, like income and food availability, and ‘stocks’ such as land tenure, social and financial assets. Gaining an income through a variety of on-farm and off-farm activities constitutes a key pillar of most rural livelihoods, allowing households and individuals to participate in markets and to benefit from resource use (Ellis 2000, Tesfaye *et al* 2011). Food access is an obvious livelihood dimension, which is often closely related to income but can also be decoupled, particularly in non-market economies and subsistence farming. Access to land and natural resources is another crucial capability because it enables the production of food for subsistence or sale, and provides other goods and services including firewood and medicinal plants. Access to land can also translate into land rents and flows of income. Such access is mediated by tenure regimes, which encompass property rights, and both formal and informal social relations and systems of authority that influence who gets access to and exercises control over land resources (Ribot and Peluso 2003). Health constitutes a particularly important asset that we include in our analysis as it is influenced both by poverty levels and livelihood strategies, including agricultural practices. We discuss each dimension in turn, highlighting what has been covered in macro-economic studies and contrasting with insights from bottom-up studies of bioenergy feedstock cultivation.

2.1. Bioenergy and income

2.1.1. Macro-perspective. Biofuel deployment affects rural income in two ways: indirectly via market-based multiplier and equilibrium effects on the macro-scale, and directly through changes in farm income or plantation wage income at the micro-scale (Arndt *et al* 2011, Lima *et al* 2011). At the macro-scale, biofuel market expansion is mostly driven

[7] See FAO (2012).

by government policies. The US and EU blending mandates are quantitatively most important, but China, India, Brazil and many other countries also have mandates, tax breaks or subsidies (Mitchell *et al* 2011). In models, the strongly increasing demand for bioenergy leads to an aggregate increase in generalized rural incomes (Golub *et al* 2012; see also section 4). If higher wages are paid in biofuel jobs they can put upward pressure on rural wages in general (Arndt *et al* 2011), which in turn may lead to increased expenditure and second-round market effects of a different kind. However, if agricultural wage levels increase, they can reduce the relative purchasing power of the non-farm poor (Golub *et al* 2012).

2.1.2. Place-specific perspective. Specific income effects depend on the production model underlying feedstock cultivation. Common production modes include: plantations; contract farming or outgrower schemes (formal, informal, in association or not with an estate (nucleus) plantation, and cooperatives); independent smallholder farming (operating mainly through spot market transactions); and subsistence farming (mainly for own consumption). Sugarcane and soy tend to be grown in large-scale operations because mechanical harvesting substantially lowers labor costs—a production model of high capital and low labor intensity. Mechanization of production can increase wages and improve labor conditions for those in skilled positions, but also reduce the number of jobs in areas where plantations substitute smallholder farming (Clancy 2013). Unskilled work in plantations is mostly seasonal, low-paid, and conditions have been judged to be sometimes inhumane, fostering exclusion (Clancy (2013); see A1 in table 1). In some contexts, sugarcane contract farmers may not even benefit economically from cultivation due to the control that the sugarcane company exercises on the costs of tillage, seedcane and transportation costs (Waswa *et al* 2009). Local production of biofuels for local use is often cited as the most promising way for bioenergy to produce livelihood benefits (Achten *et al* 2010, Ejigu 2008, Milder *et al* 2008), but relatively few peer-reviewed studies of this production model exist. Unlike feedstocks that can also be marketed for food or other products, jatropha tends to be newly deployed for energy production, both in plantations and on smaller scales. Insufficient agronomic knowledge of the plant and low profitability have hampered its success (Ariza-Montobbio *et al* 2010, Grimsby *et al* 2012, Hunsberger 2014).

The choice of feedstock affects growers' income because of the production cycle and labor requirements. Farmers who plant slow-growing feedstocks (e.g. jatropha, oil palm) must be able to defer income streams until plants produce a harvest—a situation that favors the participation of better-off farmers with other income sources or adequate savings (McCarthy 2010, Schoneveld *et al* 2011, Skutsch *et al* 2011). The scale of production also shapes income gains and distribution. Smallholders face higher risk of crop failure or lower yields than large farmers due to smaller financial resources for upfront investment and management (see A2 in table 1). However, smallholder contract farming schemes can benefit from economies of scale in certain functions (e.g. standards conformity, input supply, and crop procurement) while enjoying the advantages of family farming regarding labor management and land tenure. The realization of these benefits and their distribution between the contractor and the contracted smallholders will depend in turn on several factors, especially adequate resources and good market access of the scheme operator, low barriers to scheme entry for smallholders, the distribution of costs in the production cycle, and the existence of alternative market outlets for the producers (Gibbon *et al* 2010, Key and Runsten 1999, Kirsten and Sartorius 2002, Waswa *et al* 2009). Local competition for produce can put upward pressure on the price paid to the outgrower but can increase the risk for the scheme operator, who depends on a given level of supply to recover operation costs and maintain market position.

Contractual arrangements are thus crucial to determine the distribution of income gains and losses in bioenergy production. Policies and power relations shape value chains, determining the distribution of value added, and the inclusion, expulsion, and repositioning of actors. Often 'downstream' actors such as importers and retailers set the terms of participation, seizing a substantial part of the value added (Bolwig *et al* 2010). Uneven benefit-sharing may also result from value capture at the local nodes of the chain, by local authorities and farmer cooperatives (Rist *et al* 2010) (see A3 in table 1). Hence, inclusion is not an end in itself. When terms of participation in a global value chain are unfavorable, voluntary exclusion and the pursuit of alternative activities are preferable (Du Toit 2004, Hospes and Clancy 2011). Contract farming supplying standards-heavy value chains has yielded measurable benefits to smallholders, but only under certain and sometimes restrictive conditions (Bolwig *et al* 2013, Miyata *et al* 2009). If smallholders gain ownership in downstream processing facilities or negotiate agreements that ensure revenue sharing of value-addition, relatively equitable outcomes can be achieved (Rist *et al* 2010, Clancy 2013).

2.2. Bioenergy and food security

2.2.1. Macro-perspective. The cultivation of bioenergy feedstock interacts with food security by affecting individuals' physical or economic access to food, considering the nutritional, safety and preferential aspects of food consumption as well as the inter-temporality of access (Pinstrup-Andersen 2009). For instance, it can alter patterns of food production, household income and food affordability for farmers, workers, and the non-farm poor. These processes occur both at the macro-scale, e.g. via rising food prices, and at the micro-scale, e.g. via changes in crop cultivation patterns. Increased biofuel production (e.g. the shift from maize to ethanol production in the US) has been connected to increased food prices (in particular the maize price in Latin America) (Mitchell 2008), as well as political food crises, and even the Arab Spring (Werrell and Femia 2013). But increased biofuel production also reduces the prices of energy input needed for growing food plants, possibly also dampening food prices. Interactions between food and bioenergy markets are complex also on regional scale. One

Table 1. Examples of the effects of first-generation biofuel crops on rural livelihoods.

Bioenergy and income	
A1: mechanization *sugarcane and soy*	In rural Brazil, mechanization trends have been linked to the continuation and even worsening of social exclusion, as better-off farmers in richer regions have benefited more from producing energy crops than poorer farmers in less-productive regions. Policies have played a significant role: financial incentives through the ProAlcool program created further advantages for large-scale sugar sugarcane producers. For biodiesel, large-scale soy is increasingly dominant despite policy measures that aimed to encourage castor production from small-scale farmers (Hall *et al* 2009)
A2: capital requirement *oil palm and Jatropha*	In Jambi Province, Indonesia, oil palm production favored resource-rich farmers and excluded those with fewer resources. Participants in an oil palm scheme for Javanese settlers received a stipend for one year, after which they relied on income from casual plantation labor while waiting for their oil palm plots to mature. These wages were so low that up to half of the settlers sold their plots and moved back to Java before their oil palm became productive (McCarthy 2010). High credit requirements were also found to create dependency among Jatropha growers in Tamil Nadu, India (Ariza-Montobbio *et al* 2010)
A3: contractual arrangements *cassava*	In Banteay Chhmar, Cambodia, cassava production (a driver of deforestation) produced low incomes but high risks for smallholders, whereas middlemen and traders had considerable profit rates. A collapse in cassava prices in 2009 required smallholders that had reduced their cropping diversity to sell their land to repay debts and acquire food (Hought *et al* 2012)
Bioenergy and food security	
B1: food access *oil palm*	In Papua, Indonesia, the establishment of 20 000 ha of oil palm plantations on former clan-controlled forest land led to a significant decline in food access for the indigenous population, mainly because of decreased opportunities for hunting, fishing, and collecting forest resources, and reduced access to farm land (Obidzinski *et al* 2012). Few people were able to compensate for this loss of direct food access through paid employment on the plantations, and individual oil palm growing was not possible. Hence 100% of the 'former landowners' and 'customary users' interviewed experienced reduced access to food, while 93% experienced an overall negative change in livelihoods. Among plantation workers, 56% experienced an increase in consumption. But 46% still reported an overall negative change in livelihood
B2: food production *Jatropha*	In Tamil Nadu, India, Jatropha growing was found to significantly reduce food production (edible oil, staples and vegetables) both for sale and household consumption, as Jatropha replaced food crops and occupied more than 50% of the landholding. It also reduced the availability of crop residues for animal fodder. Crop diversity was reduced as mature Jatropha was grown as a monoculture. Reduced food production was not offset by higher income; at observed yields, economic returns for growing Jatropha were consistently negative. Planting Jatropha decreased livelihood diversity and made the income of smallholder farmers more precarious (Ariza-Montobbio and Lele 2010)
Bioenergy and land tenure	
C1: loss of customary land *Jatropha*	In Ghana, a foreign biofuel company acquired large contiguous areas of land without regard to customary land rights. Sixty-nine households lost land without consent or compensation. Loss of access to farmland and forests, and in turn to food and various income sources, disproportionately impacted women and migrant farmers. In contrast, plantation employee households gained stability and security in income flow. Social conflict reportedly increased as plantation workers became less able to help with communal labor (Schoneveld *et al* 2011)
C2: institutional shortcomings *oil palm*	In Central Kalimantan Province, Indonesia, the establishment of oil palm plantations and palm oil mills since around 2000 has led to a significant deterioration of local water resources, with negative effects on fish stock, rice farming, access to drinking water, and health (skin disease) in three villages (Klocker-Larsen *et al* 2012). Environmental laws exist to protect water resources and to ensure that Environmental Impact Assessment are performed prior to obtaining concession permits, and a water law stipulates water use rights—including establishing recognition of customary rights. These environmental and social regulations were not implemented in practice; the losses of the villagers were not compensated and their grievances not addressed

Table 1. (Continued.)

Bioenergy and health	
D1: burning biomass *sugarcane*	Burnt sugarcane harvesting in Brazil has been found to increase blood pressure among healthy male workers (Barbosa *et al* 2012). It has also been associated with higher incidence of respiratory problems and reduced lung function compared to non-harvesting periods, not only among plantation workers but also among residents of a nearby town (Prado *et al* 2012). In Sao Paolo province, the onset of biomass burning led to a 30% increase in asthma-related hospital admissions in a neighboring city (Arbex *et al* 2007). Hospitalizations due to asthma were also significantly higher during sugarcane field burning in Louisiana, United States (Boopathy *et al* 2002)
D2: water pollution *oil palm*	In three sites in Kalimantan and Papua, Indonesia, large-scale clearing of forest for oil palm plantations led to siltation of waterways and swamps used as sources of fresh water for domestic needs (Obidzinski *et al* 2012). In eastern Papua, river water could no longer be used for domestic use due risk of contamination from pesticides and herbicides. Air pollution from dust and smoke coming from the plantation and mill sites were also considered significant hazards in two sites. Respectively, 24%, 27% and 31% of respondents in the three sites reported an increase in human disease after the establishment of oil palm plantations

modeling study suggests that biofuel expansion can reduce the area cultivated with traditional export cash crops (in Mozambique and Tanzania), but can lead either to a decrease (Mozambique) or an increase (Tanzania) in food production depending on local factors such as land availability and the labor intensity of traditional cash crop production (Arndt *et al* 2011). Appreciation of the real exchange rate caused by the rapid expansion of biofuel exports can explain this dynamic. In both cases, appreciation crowds out traditional export crops that experience a price reduction in domestic currency. In Tanzania some of this production is then substituted by food production; in contrast, biofuel production substitutes for food production in Mozambique. Other equilibrium effects would be an increase in food prices in Mozambique, and a decrease in Tanzania, and a reduction of income of traditional cash crop producers and workers.

2.2.2. Micro-perspective. The relationship between feedstock cultivation and food security at the micro-scale is equally complex. Extended cultivation of cash crops has been identified as a key factor determining local food security (Bolwig 2012, Ericksen 2008, Fafchamps 1992, Von Braun 1995); this is likely to apply to bioenergy feedstocks as well. On one hand, it may increase food access by raising crop revenue, e.g. by providing better access to fertilizers, incentivizing an increase in volume, and reducing the unit cost of production. And it may lead to savings that become reinvested in food production, non-farm employment, or children's education for longer term benefits (Davis *et al* 2009). The income obtained from biofuel production can be used to buy additional food thereby increasing household nutrition. On the other hand, it may reduce own food production by diverting scarce factors of production away from food crop farming, reducing food access (Obidzinski *et al* (2012)—B1 in table 1). Also the timing of a feedstock's peak labor requirements can lead to decreased food production in situations of labor scarcity in a smallholder context (Mingorría and Gamboa 2010). These outcomes are shaped by place-specific gender dynamics, market design, and food price volatility which together render predictions of bioenergy deployment on food security uncertain (Alene *et al* 2008, Bolwig 2012, Raynolds 2002). Evidence suggests that the risks associated with relying solely on cash crop income for food access may render a partial self-sufficiency strategy more attractive (Fafchamps 1992). Partial cash cropping can provide direct benefits in terms of agricultural development to all farmers, including those who do not grow cash crops (Govereh and Jayne 2003), and also result in higher agro-biodiversity and *in situ* conservation (Bangwayo-Skeete *et al* 2012).

2.3. Bioenergy and land tenure

2.3.1. Macro-perspective. Biofuel deployment leads to a rise in land value and can reorganize tenure regimes. Policies, such as blending mandates, contribute to an appreciation of land value within the mandated region and world wide, depending on the degree of trade liberalization (Banse *et al* 2008). An increase in yield productivity can make land formerly considered 'marginal' commercially attractive, leading to further expansion of biofuel feedstocks.

2.3.2. Micro-perspective. Forced or voluntary displacement from other land uses, such as subsistence agriculture, forest commons or livestock grazing, often leads to loss of customary land rights and land access conditions (Schoneveld *et al* (2011); see C1 in table 1), as well as to indirect land-use change (Lima *et al* 2011). At the local scale, households and communities without formal land titles can see their access to land compromised, or be excluded from production schemes and their associated benefits (Skutsch *et al* 2011). In some circumstances, women loose informal access to land and resources more easily than men (Schoneveld *et al* 2011). Subsequently, women see their household and farm labor-time budgets disproportionately increase (Julia and White 2012, Mingorría and Gamboa 2010, Skutsch *et al*

2011). Such distributional effects derived from the interplay of biofuel deployment and land tenure can be felt at distinct spatio-temporal scales, some being experienced even before biofuel deployment occurs, including displacement of 'landless' or informal tenure holders through investments or land grabs (Baka 2013).

The benefits, costs and distributional consequences of the interplay between bioenergy and land tenure can again be related to the production model. In Mozambique, Jatropha cultivation in outgrower schemes allowed smallholders to accrue land rents, whereas the land rents of sugarcane plantations were transferred to absentee investors (Arndt *et al* 2009). Where large-scale bioenergy production is organized through policy incentives and land-use planning from the top-down, the rural poor can become vulnerable to dispossession if they do not hold official land title (Cotula *et al* 2008, Vermeulen and Cotula 2010). Traditional land owners and communal use of resources can experience restrictions as a result of both plantations and outgrower schemes, with households that previously relied on forest resources for income and food shifting to other sources of livelihood (Julia and White (2012), Obidzinski *et al* (2012); see also C2 in table 1). The transfer of land rights to large-scale operations reduces income and livelihood opportunities for local communities and leads regularly to conflict over land rights (Marti 2008, McCarthy 2010). In contrast, land tenure security may buffer against social conflict and facilitate biofuel and agricultural developments (Smalley and Corbera 2012). In situations where land is relatively plentiful and infringement on traditional land rights is scarce, biofuel deployment can lead to changes in land use without necessarily triggering social conflict. For example, Jatropha cultivation in Zambia did not seem to restrict local food crop production, although it still produced unequal economic outcomes (German *et al* 2011). In summary, biofuel deployment often but not always compromises land tenure of some groups, usually those with weaker position. The effect is distinctly shaped by production model, politics and power relations, and pre-existing land use.

2.4. Bioenergy and health

2.4.1. Macro-perspective. Biofuel plantations can indirectly improve public health if additional income streams enable financial access to drugs and health care. Food insecurity has direct impacts on public health (Yngve *et al* 2009). Hence, it is possible that health and food security could deteriorate in a vicious cycle.

2.4.2. Micro-perspective. Health enables household members to engage in crop cultivation and other social and economic activities. Plantations can facilitate the transmission of malaria or dengue by allowing their vectors to survive throughout the year or find more suitable breeding and survival conditions (Tanga *et al* 2011). Exposure levels to herbicides and other agricultural chemicals and their composition are insufficiently monitored (Mink *et al* 2012, Williams *et al* 2012) and are often unknown to workers (Gupta 2012). Social relations can also be eroded by biofuel deployment. In Ghana, plantation workers had insufficient time to help with communal labor leading to social conflict (Schoneveld *et al* 2011) and in Guatemala, households employed by oil palm plantations dedicated less time to communal activities (Mingorría and Gamboa 2010). Biomass burning in sugarcane plantation leads to detrimental health outcomes (Goldemberg *et al* 2008) including respiratory diseases, both among workers and in neighboring towns (D1 in table 1).

3. Livelihood outcomes summarized

Section 2 has reviewed studies that illustrate actual or potential impacts of bioenergy feedstock deployment on rural livelihoods, considering global and local dynamics. Global and regional models can already capture potentially relevant income and food security effects, and can identify groups that profit or lose from bioenergy deployment. However, they fall short of scrutinizing changes in capabilities and assets, and remain restricted in their treatment of distributional equity due to crude resolution of distributional dynamics. At the micro-scale, research reveals that the production model plays a key role in determining income gains or losses, food security, land tenure conflicts and health effects for workers and communities. The smallholder production model benefits livelihoods more when it is labor intensive, when it enables smallholders to participate in value creation along the supply chain, and when it is pursued alongside food production. Large-scale production may involve higher land productivity, but also requires considerable financial and human capital, increasing the risk that income inequalities will result, sometimes mirrored in health impacts and social exclusion. While plantation workers usually experience increased income, reductions in food production and community activities due to time constraints must also be accounted for. Those who obtain or keep formal land rights tend to profit from bioenergy deployment by reaping a higher land rent, while those who lose formal or—more often—informal land rights and access to land and its ecosystem services see a reduction in their land-related livelihoods. This can be particularly acute if deployment takes place through plantations that do not offer new opportunities to the dispossessed. As those with formal land rights usually have more capital to start with, and those without rights have less access to institutions and money, distributional inequities are often increased by formalization and consolidation of land rights. These main effects are summarized in the conceptual diagram of figure 1.

Assessing how these effects are distributed is crucial. As an example, a recent study of oil palm production in Indonesia by independent growers and outgrowers contracted to nucleus estates reveals aggregate and distributional effects that generate winners and losers (Obidzinski *et al* 2012). Smallholders reported increased income from producing oil palm and non-participants benefited from spillover demand effects in other economic sectors. However, these economic benefits were unequally distributed: 'former land owners'

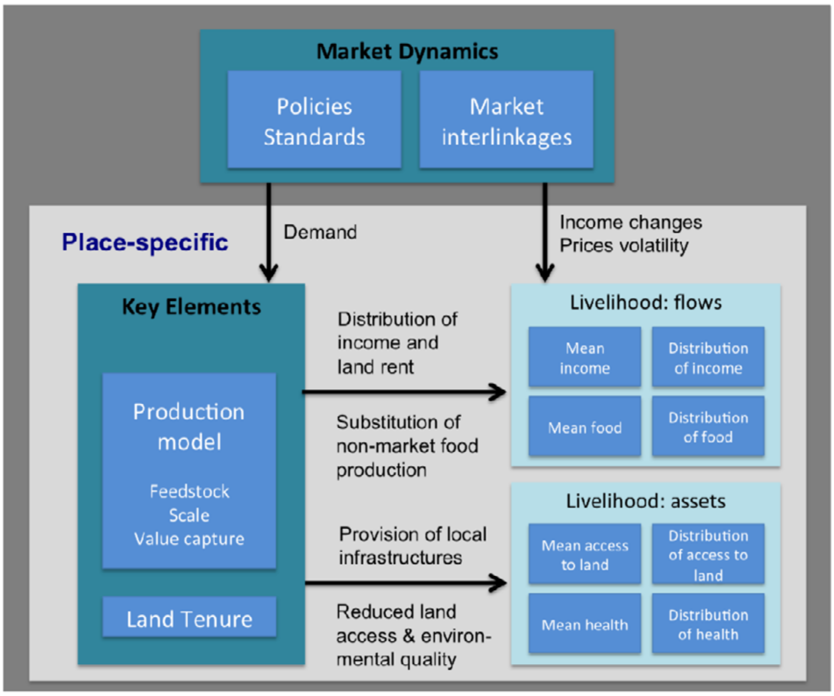

Figure 1. Biofuel deployment affects livelihoods via global and local processes.

and 'customary land users' lost while (migrant) landowners with formal title gained. Access to capital reportedly served as a barrier to participation and whilst most stakeholders reported improved access to food, oil palm replaced cash crops and some food crops on smallholder land. Land values also increased, benefiting those with plots, but conflicts over land occurred, both between communities and companies and between traditional landowners and migrants. The loss of customary rights to cropland, mentioned by over half (53%) of respondents in one site, was more likely to affect households without formal land titles. The expansion of oil palm also reduced access to forest products and services—including fallows for shifting agriculture—affecting women's livelihoods more than men's. Oil palm production reduced the quality and quantity of available fresh water, caused soil erosion and water logging, and increased flooding. If one looked only at aggregate outcomes, this case would suggest that mildly positive outcomes occurred in three of the four livelihood dimensions. But once distributional outcomes are also considered, the analysis would suggest that inequities were perpetuated or widened in all four livelihood dimensions. Particularly for land and income, gains (for some) have been offset by increased inequality in the distribution of outcomes (figure 2).

4. Reconsidering livelihoods in integrated assessments

In spite of this growing evidence that bioenergy deployment has effected or may effect income, food security, land tenure and other assets, global integrated assessment studies consider livelihoods only generically and are operationalized by focusing on global market effects. Golub *et al* (2012) investigate the livelihood impact of global land-based climate policies (not bioenergy deployment), focusing on income and food security. They find that restricting deforestation and agricultural expansion for food production leads to increased income and food availability in farm households due to price appreciation, but mostly a decrease in real income and food availability for the non-farm poor. As biofuel production puts similar pressure on arable land and food production, it is likely to produce similar livelihood effects on the agricultural food-sector and non-farming livelihoods. Golub *et al*'s study is the first to try to quantify livelihood effects of climate policies systematically and globally. However, by modeling a representative farming household it assumes complete and equal value capture by rural households, and underestimates the distribution of benefits and costs at the micro-scale, e.g. by not representing livelihood assets.

Our analysis demonstrates that deployment schemes do not only affect aggregate income and food availability. Schemes also impact land tenure and the quality or availability of other assets, particularly finance and health. More importantly, the design of deployment schemes also has distributional consequences across the four outcome dimensions we considered (income, food, land, and health). We therefore argue that to be policy relevant, integrated assessments should comprehensively consider livelihood outcomes of bioenergy deployment, summarized in table 2. Our analysis suggests a likely tension between aggregate and equity impacts that needs to be made explicit in bioenergy assessments to better support decision-making.

A first attempt to bring livelihoods into integrated assessment models could include introducing distributional parameters. For example, distinct parameters could represent the fractions of households (percentage of affected

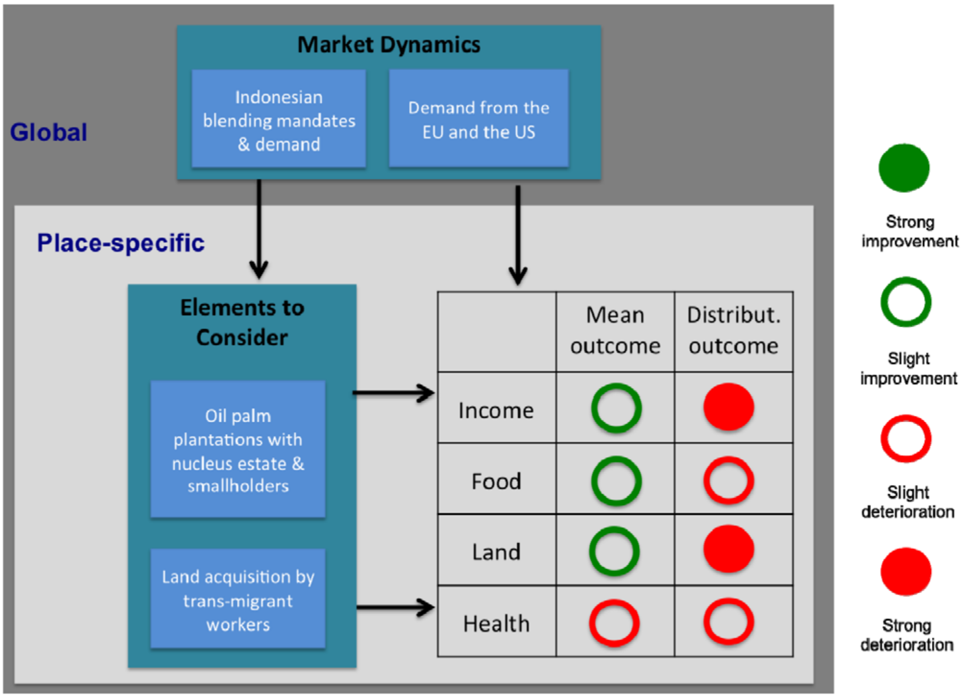

Figure 2. Assessment of livelihood outcomes for smallholder oil palm producers in Indonesia, based on qualitative data reported in Obidzinski *et al* (2012). The color-coding represents our qualitative evaluation of data given in the literature and remains indicative. Changes are shown relative to *a priori* conditions.

Table 2. Possible livelihood outcomes from bioenergy deployment. Normal text denotes benefits or harms considered by integrated assessments, notably Golub *et al* (2012). Bold text denotes outcomes not included in integrated assessments.

Livelihood aspect	Benefits	Harms
Income and occupation	Higher total income Multiplier effects	Lower purchasing power of non-farm poor **Lower income of displaced people** **Exclusion of non-monetary occupations**
Food	Higher security with higher income	Lower food access for non-farm poor **Reduced food supply from subsistence farming**
Land	**Higher land rent for formal land owners**	**Lower access to land and ecosystem services, particularly for those without land titles**
Other assets	**New education, health and production infrastructure** **Higher savings**	**Detrimental health impacts** **Social conflicts** **Indebtedness**

households) with improved or reduced (A) income, (B) food access, (C) land tenure and (D) health as a result of deployment schemes. We are aware that such parameters are highly uncertain and would still be insufficient to cover all place-specific effects. But the current practice of ignoring the distributional outcome is also a strong normative choice that can lead to misguided policy. Integrated assessment would turn from optimization models towards multi-criteria assessments that rely on scenarios that take into account potential distributional consequences at household and community levels: the combined outcome in efficiency, GHG emissions, livelihoods, and equity could be the more complex but also the more comprehensive basis for policy decisions (Creutzig and Kammen 2009). One could still object that aggregate livelihood and equity issues are problems that can be analyzed and solved independently from each other (this is the main claim of the second welfare theorem), but our analysis clearly highlights that these issues remain entangled. The choice of production model, the underlying and evolving land tenure regimes, global biofuel markets and equilibrium effects on food markets, all affect both aggregate and distributional outcomes. Hence, equity should be included in a full set of criteria for bioenergy assessments. It is likely that this conclusion is also valid more generally for other climate and energy assessments, such as those focusing on other technological but also behavioral options.

Our analysis remains limited in focusing on first-generation crop-based biofuels. Jatropha is however sometimes considered a second-generation biofuel, but is similarly prone to detrimental distributional issues (Findlater and Kandlikar 2011) that need to be explicitly considered in comprehensive assessments. More generally, we suspect that second-generation bioenergy plantations would on the one hand provide higher income and land rent with higher yields compared to first-generation biofuels but again would marginalize local populations that live from informal land tenure. The utilization of residues and the cascade utilization of biomass is however also seen as a promising route for providing energy (Haberl and Geissler 2000, WBGU 2009) and could improve existing livelihoods. Future research should explore this direction.

Finally, we recognize that our analysis does not tackle a key conundrum: how can livelihoods be assessed globally if each deployment scheme has effects that depend on various place-specific factors? A comprehensive assessment by human geographers and agricultural economists could elucidate which kind of distributional livelihood effects need to be accounted for, and which biofuel deployment schemes (crops, institutional arrangements, land tenure schemes) have more advantageous outcomes. The diversity of approaches, methods and analytical categories could be roughly mapped using integrated livelihood assessment figures resembling figure 2, and assessments could rank deployment scenarios in terms of their impact on livelihood dimensions. We see ample opportunity to soft-couple integrated assessment models with local livelihood analyses and CGE and partial equilibrium sector models. This could elucidate both risks and opportunities of bioenergy deployment for livelihoods. The ultimate art is to ensure that pathways and production models not only produce positive aggregate outcomes, but that they simultaneously respect and improve place-specific livelihoods. If specific deployment schemes are unlikely to achieve these goals, they should not be pursued.

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