Mitig Adapt Strateg Glob Change (2014) 19:773–788
DOI 10.1007/s11027-013-9485-8

ORIGINAL ARTICLE

Low carbon emission development strategies for Jambi, Indonesia: simulation and trade-off analysis using the FALLOW model

Rachmat Mulia · Atiek Widayati · Suyanto · Putra Agung · Muhammad Thoha Zulkarnain

Received: 22 February 2013 / Accepted: 21 June 2013 / Published online: 5 September 2013

Abstract Economic growth in rural areas has to align with preservation of land uses that optimise environmental services. This means that trade-offs between economic and ecological priorities need to be understood, quantified and managed. We aimed to estimate the trade-off in the Tanjung Jabung Barat district of Jambi province Indonesia, where traditional agroforestry systems on both peat and mineral soils and logged-over forests give way to monocultural plantations of pulpwood and oil palm (*Elaeis guineensis*). Simulations of a 30-year time period of four scenarios using the FALLOW (Forests, Agroforests, Low-value-Landscape, Or, Wastelands) model show that a business-as-usual scenario of economic growth unhindered by the application of conservation scenarios will lead to high carbon dioxide CO_2 emissions. The forest and agroforest protection scenario, with moderate assumptions for peat-based emissions, had opportunity costs of 3–100 USD/t CO_2e. This occurred especially when the establishment of oil palm plantations, which are currently the most profitable land use option in the area, is directed solely to under utilized mineral soils. The high trade-off values are difficult to reconcile when relying only on C trading mechanism to offset economic opportunity costs of not converting forests and/or agroforests to plantations. We conclude that law-based protection of existing forests, investment in intermediate intensity agroforestry options that utilize locally adapted trees and do not require drainage of peatlands, and re-introduction of tapping Jelutung (*Dyera sp*) latex as non-timber peat forest product, are needed in the Tanjabar district to provide options that are sustainable from both ecological and economic perspectives.

Keywords Agroforest · C emission · FALLOW model · Land use scenario · Oil palm · Trade-off

1 Introduction

If the primary focus of efforts to Reduce Emissions from Deforestation and Forest Degradation (REDD) is on protecting 'forests' from deforestation or degradation, there is a great risk of emission displacement and leakage to high carbon (C) stock areas outside the recognized forest

R. Mulia (✉) · A. Widayati · Suyanto · P. Agung · M. T. Zulkarnain
World Agroforestry Centre, SEA Regional Office (ICRAF), Jl. CIFOR,
Sindang Barang, Bogor, PO Box 161, Bogor 16001, Indonesia
e-mail: rmulia@cgiar.org

(Ekadinata et al. 2010). Even where REDD implementation efforts at project scale within the forest boundary might appear to be successful, scrutiny of a larger area in the landscape may reveal that net C emissions due to land use prevail (van Noordwijk and Minang 2009). Empirical data have shown that a wide range of leakage levels, from the negligible to the more substantial, can occur, depending on the ongoing conservation program in various regions (Murray et al. 2004). The rural landscape beyond institutional forest boundaries may consist of high-biomass land uses such as complex agroforests that may not be classified as ‘forest’ as such; whereas monoculture plantations, such as timber or oil palm (*Elaeis guineensis*), may fit the definition of ‘forest’ and have lower terrestrial biomass. A larger accounting and accountability area and a broadening of the definition of ‘forest’ may offer a solution to the challenges facing REDD implementation, and maintaining or developing C stock at the landscape level. The REDD++ scheme or REALU (Reducing Emissions from All Land Uses) includes aspects such as emissions in areas outside forests and in peat lands that were not integrated into the earlier REDD schemes (namely, RED (Reducing Emissions from Deforestation), REDD, and REDD+ (Reducing Emissions from Deforestation and Forest Degradation)) (van Noordwijk et al. 2009). In this scheme, four pillars for the success of reducing emissions at the landscape level are identified. These include REDD, REPeat (Reducing Emissions from peat areas), REStock (increasing the stock of trees in the landscape), and REGG (Reducing Emissions from Greenhouse Gas due to agricultural activities) (van Noordwijk et al. 2009).

The landscape mosaic in the district of Tanjung Jabung Barat (Tanjabar), in the Indonesian Jambi province of Sumatra is complex, and involves both peat and non-peat lands. Threats to the viability of forest and high-biomass land uses arise from land conversion into plantations or agricultural crops. There are several existent types of tree-based systems in place, usually involving rubber (*Hevea brasiliensis*), coconut (*Cocos nucifera*), betel nut (*Areca catechu*) or coffee (*Coffea liberica*) as a predominant or secondary product. Oil palm has been flourishing in mineral soil area since 1980s in line with the plantations established by government, private companies and ‘people’s plantations’ with Nucleus Estate Smallholders (NES). In the peat area, oil palm started to be planted around early 2000s as smallholder practice. Although new to the local people, it has quickly gained popularity due to its high economic return when compared to other livelihood options (Sofiyuddin et al. 2012). Conservation programs to protect forest or high-density land use on the one side and the need for economic profit on the other produce a trade-off between economic and ecological gains, which is as yet revealing few opportunities for a win-win solution. Converting high-biomass land uses into monoculture plantations or mining projects offers a higher economic return but reduce environmental integrity, while conserving existing forests reduces income opportunities. Despite its high profitability, monoculture practice in oil palm plantations reduces biodiversity like fauna (Posa et al. 2011; Campbell-Smith et al. 2011) and the kinds of product diversification found in agroforestry practices. During the last decade, however, an increase in the potential uses of oil palm, high and stable global demand, and weak legal implementation of forest or high-biomass land use preservation and conservation programs, have contributed to a massive conversion of agricultural crops and local agroforestry sites in Indonesia into oil palm plantations (Bhagwat and Willis 2008). This takes place in both small and larger scale practices, as managed by smallholders and large agribusiness estates, respectively. The double production target proposed by central government for 2020 seems to implicitly support this massive conversion, and shows no clear consideration for other priorities such as national food security, biodiversity protection and C conservation (Koh and Ghazoul 2010).

A land use dynamics model that integrates the various components of the rural landscape and their interrelationships can be used to measure the impact of land use strategies on the economic and ecological prosperity of the local people living in the landscape. Among the various landscape dynamics models available (as reviewed by Lee et al. 2003; Messina and Walsh 2001; and Soares Filho et al. 2008, for example), we consider the FALLOW (Forests, Agroforests, Low-value-Landscape, Or, Wastelands) model (van Noordwijk 2002; van Noordwijk et al. 2008; Suyamto et al. 2009) to be the most comprehensive because it explicitly considers both the biophysical and socio-economic aspects and, to some extent, simulates the knowledge of agents as both a constraint and a dynamic property in learning landscapes. Model simulations with a spatially explicit approach can produce useful maps that depict what occurs in the landscape both spatially and temporally. The outputs can serve as a basis for discussion of the impact of different development strategies or how to adapt to future changes. The use of simulation models is thus a type of projection method, though it does not provide exact predictions of future situations. It does, however, provide assistance in designing appropriate development and implementation strategies.

We aimed to use the FALLOW model to estimate economic and ecologic impacts arising from the implementation of land use development scenarios that will determine the future of rural landscape in the Tanjabar district. Scenarios considered include the purely profit-oriented (such as allowing the establishment of new oil palm plantations across the landscape, including in peat areas replacing existing forests), and those that aim to maintain biodiversity and product diversification by supporting the viability of the remaining forest and native agroforestry practices.

2 Materials and methods

2.1 Site description

The district of Tanjabar is part of Jambi Province (Fig. 1a), which is situated in the eastern part of Sumatra, Indonesia. This is a coastal area with the geographic location of 7.35S–102.64E and 1.45S–103.58E. The district consists of approximately 500,000 ha of rural land, with a population of about 270,000 people, 77 % of whom were farmers in 2009. The annual population growth rate is 1.9 %, and per capita income is 1000–1300 USD. The landscape is decorated with peat lands, which constitute about 40 % of the total area of the district, and are located mostly in its northern part (Fig. 1b). The depth of peat varies across the peatland of Tanjabar, with the deepest found in disturbed peat swamp forest area of approximately 290 cm (Rahayu et al. 2011). The peat lands have mostly been converted to tree-based systems, except for a small peat forest known as Hutan Lindung Gambut (HLG), which is currently designated as a protection forest for ecological and hydrological reasons through the decree of Minister of Forestry in 2009. The remaining forests are located mainly in the southwest of the district, which includes the Bukit Tigapuluh National Park (BTNP) and a part of the former management unit of production forest known as the Kesatuan Pengelolaan Hutan Produksi (ex-KPHP) (Fig. 1b), which is categorised partly as limited production forest and partly as production forest. Ex-KPHP is not assigned for industrial plantation or any other specific use. Industrial forest plantations with acacia trees, *Acacia mangium* on mineral soils and *Acacia crassicarpa* on peat, known as Hutan Tanaman Industri (HTI), dominate the production forest area of the district and covers 35 % of the landscape. Oil palm (*Elaeis guineensis*) exists as large scale plantations in mineral soil area and as smallholder in non-peat soil area.

2.2 Tree and crop-based systems in the district

For agricultural crops, smallholders cultivate maize and rice for staple foods as well as soy beans, cassava, groundnut, and other vegetables. Different types of tree-based systems also exist and consist mainly of rubber agroforests: either in simple form with a small number of non-rubber species, or in more complex form with 5–20 non-rubber species also growing in a rubber garden (Khususiyah et al. 2011). Other important tree-based systems include ‘excelsa’ coffee and coconut agroforests, and oil palm plantations as the new commodity

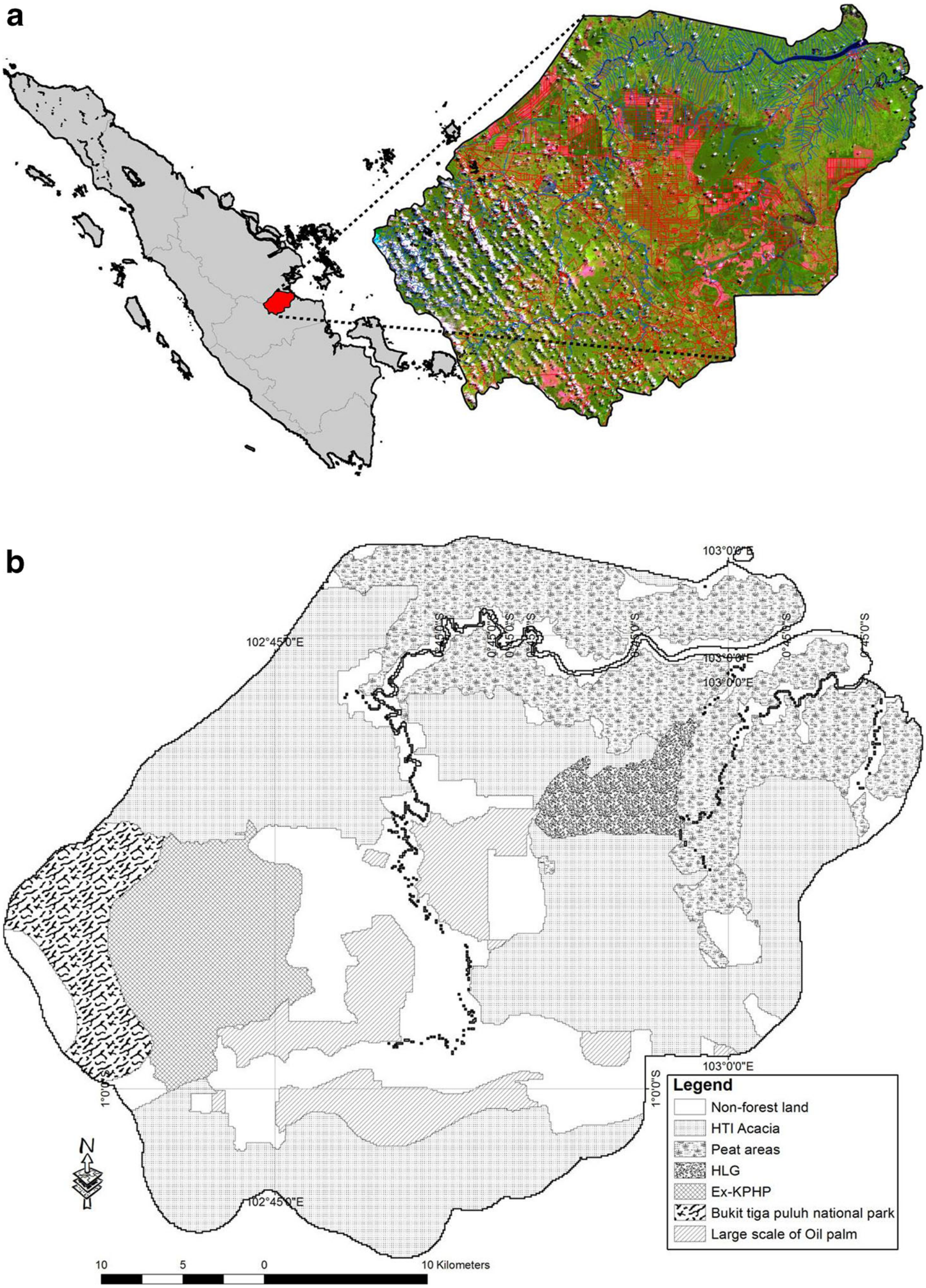

Fig. 1 Location of Tanjabar district in Jambi province, Sumatra, Indonesia (**a**) and area boundaries within the landscape (**b**)

introduced into the landscape. Smallholder rubber production system (*Hevea brasiliensis*) are still traditionally managed and farmers tend to use low quality seedlings with or without fertilizers and weed-killing applications. In the more complex forms of rubber agroforestry, farmers usually cultivate rubber together with fruit or timber trees such as pulai (*Alstonia sp.*) and tutup (*Macaranga hypoleuca*). This product diversification can help to maintain the income of smallholder farmers when they are faced with a harvesting or marketing problem in relation to one specific commodity. Coconut and betel nut (*Areca catechu*) are common multipurpose tree species that are often introduced into the system, either as important products or as a live fence or marker of land tenure. The main product of the coconut system is copra, which was an important commodity in Tanjabar during 1980s to 1990s (Khususiyah et al. 2011). Off-farm jobs include labour on the large-scale oil palm or acacia plantations.

2.3 FALLOW model

The FALLOW model was designed to simulate land cover change at the landscape level, driven by stakeholder decisions on labour and land allocation (van Noordwijk 2002; Suyamto et al. 2009). Initially constructed for the simulation of a simple 10×10 cell landscape, the model can now handle input maps obtained from Landsat satellite images. The default plot size is 1 ha with possible modification depending on the objective of the study and adjustments to input parameters. The current version of the model is coded in PC-Raster simulation language (http://pcraster.geo.uu.nl/). The model considers various external drivers that can influence stakeholders to make decisions in relation to the available land use options. These include both biophysical and social economic aspects, such as: i) market mechanisms and relevant regulation interventions, articulated through commodity prices, costs, and harvesting labour productivities; ii) development programs, articulated through counselling, subsidies, infrastructures (settlements, road, market, processing factories), and land-use productivities; and iii) conservation programs, articulated through forest reserves as zones prohibiting local agricultural activities. Stakeholders consider all these factors when making decisions on labour and land allocation. Decisions can also be influenced by experience of the past and current year's profits, suggestions from others, as well as cultural/traditional values (for example, a family tradition of cultivating a certain land use option regardless of economic conditions).

With the FALLOW model, the impacts of land use strategy on the economic and ecological levels are represented by smallholder per capita income and standing C stock, respectively. Income does not include funds obtained by agribusiness estates in the landscape or from off-farm jobs. There are four core modules of the FALLOW model with their interactions (Lusiana et al. 2012) (Fig. 2). These basically describe the relation between stakeholder decision-making and a spatial pattern of land use change, with the consequences for productivity and households. A more detailed description of the model is given in van Noordwijk (2002) and Suyamto et al. (2009).

2.4 Input maps and parameter values

The FALLOW model needs inputs in map format and parameter values. At least ten maps should be provided prior to simulation. These include land cover map and those describing biophysical conditions of the simulated landscape such as soil fertility and plantation suitability map (Suyamto et al. 2009). Parameter values include those related to economic, biophysical and demographic aspects. For this study, the land cover map was produced from Landsat satellite imagery following hierarchical object-based classification methods (Widayati et al. 2011). The

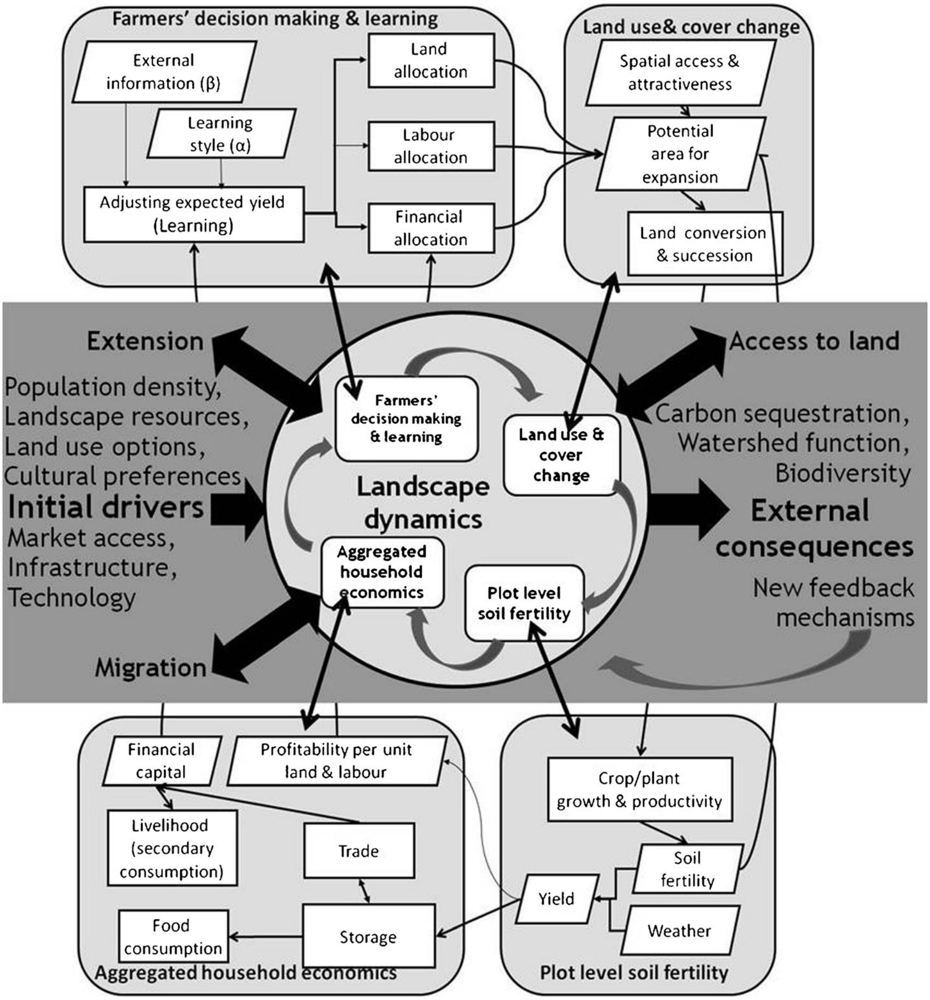

Fig. 2 The four core modules of the FALLOW model that relate farmers' decision-making to a spatial pattern of land-use change, with consequences for productivity and households

biophysical data such as C stock were obtained from the measurement and study by Rahayu et al. (2011). The economic data were obtained from Sofiyuddin et al. (2012).

For the simulation, we used a land cover map of the year 2009 which uses a ten-step classification (Table 1). There were different types of forest in the landscape, including lowland forest, peat-swamp forest and mangrove forest (although the latter exists only as small strips in coastal areas). These different types of forest were grouped together under the single classification of 'forest'. This grouping was based on the relatively comparable standing biomasses among the different forest types and because no non-timber forest product (NTFP) to be harvested from these forests was simulated. Anecdotal information shows that local people collect rattan and honey from the forests in small amounts, mostly for personal use rather than as a business undertaking. For agricultural crops, due to lack of data and relatively small areas they occupy in the landscape, we propose that the biophysical and economic properties of soybean (*Glycine max*), cassava (*Manihot utilissima*), groundnut (*Arachys hypogaea*), and other vegetable systems are not different from those of maize.

We therefore classified them under the single category: crops. Six different tree-based systems were simulated (Table 2), with some being differentiated according to their growing conditions in peat or non-peat soils, and others undifferentiated. The differentiation of oil palm in peat and in non-peat soil was made because of the significant difference in their economic values, while this is not the case with rubber production system (*Hevea brasiliensis*). Coffee gardens exist exclusively in peatland area in Tanjabar and the most popular variety planted is *Coffea liberica var. dewevrei*, also known as Excelsa. Excelsa coffee grows well in mature peat and is characterized by bigger beans compared to robusta (Khususiyah et al. 2011). Each type of tree-based system was divided into 4 production stages: 1) the pioneer stage, between the planting period and the end of the vegetative cycle; 2) the early stage, at the start of the generative cycle; 3) the mature stage, when the production is relatively stable; and 4) the post production stage, when production is declining.

As state forest lands are usually considered to be an open access area by the local community, the central government applies a Kesatuan Pengelolaan Hutan (KPH, Forest Management Unit) mechanism that classifies the state forest lands into management areas, according to their basic function and the designated use of the forests (Kartodihardjo et al. 2011). An example of KPH types is KPHP (Kesatuan Pengelolaan Hutan Produksi – Production Forest Management Unit) that is designated for production. KPH is expected to provide a better forest management system for Indonesia's forests and applies forest management at the subnational level. In Tanjabar, the scheme is expected to gradually change the perception of open access for the large parts of the state forest land. Despite the central government efforts to protect and rehabilitate the remaining state forest lands, the legality and legitimacy of forest ownership itself remains a contentious issue. The central government has sought to strengthen the legal position of the forests through the finalization of the forest gazettement process, but its legitimacy is still being challenged by the local government and communities. We simulated the case when the ex-KPHP is not legally protected and may be converted into plantation by the local smallholders or it is legally protected with a strict regulation implementation (Table 3).

Table 1 Land cover classification in the FALLOW model for Tanjung Jabung Barat. Two types of agriculture and six types of tree-based systems are were simulated

Class	Land cover	Remarks
1	Settlement	
2	Forest	The forest category groups together forests in non-peat and peat soils, as well as swamp and mangrove forests
Agricultural crops		
3	Rice (*Oryza sativa*)	The crops category groups together all crops other than rice
4	Crops	
Tree-based systems		
5	Rubber agroforest	This category groups rubber agroforest in peat or non-peat, both simple and more complex forms
6	Oil palm peat	Oil palm plantations in peat
7	Oil palm non-peat	Oil palm plantations in non-peat
8	Coffee agroforest	Usually mixed with a few betel nut trees
9	Coconut agroforest	This system groups together coconut agroforest (usually with betel nut) and monoculture, as well as home gardens that usually consists of coconut and betel nut
10	Acacia	Only in industrial plantation (HTI) areas

Table 2 Observed time-average C stock and yield of each land use type in Tanjung Jabung Barat. As the scenarios studied did not involve change in areas allocated to the industrial timber plantations (HTI); no yield, labour and income estimates were considered

Category	Land cover type	Time-averaged C stock (ton ha^{-1})	Return to labour (USD pd^{-1})	Return to land (USD ha^{-1})	Yield (ton ha^{-1})	Yield price (USD ton^{-1})	Income (USD ha^{-1})
Forest	Pioneer forest	17	–	–	–	–	–
	Young secondary forest	96	–	–	–	–	–
	Old secondary forest	162	–	–	–	–	–
	Primary forest	202	–	–	–	–	–
Crop	Rice	1	6.35	404	1.33	667	887.11
	Crops	10	6.96	595	1.00	222	222
Tree-based	Rubber	58	7.51	1731	0.54	1778	960.12
	Oil palm peat	39	16.06	5866	13.51	133	1796.83
	Oil palm non-peat	40	17.29	7615	18.87	156	2943.72
	Coffee	26	8.91	5722	0.68	1833	1246.44
	Coconut	32	8.34	2002	1.22	422	514.84

C stock in the rubber production system (*Hevea brasiliensis*) is higher than that measured in other tree-based systems (Table 2). From the economic aspect, oil palm cultivation was the most profitable agricultural option, followed by coffee, rubber and coconut systems. In general, tree-based systems offer higher profits than annual crops (Table 2).

2.5 Developed scenarios and model simulations

Table 3 summarises four land use scenarios. The FALLOW model simulations show the effects of likely changes to current conditions informed by the planning standpoints of different stakeholders in the Tanjabar district that include local departments such as forest and agricultural department: 1) The 'Business as Usual' (BAU) scenario reflects the current trend, with the possibility that the remaining peat forest (HLG) will be opened for conversion into smallholder plots. The only protected forest is the BTNP. The rest of the forest on non-peat soils in the southern area (ex-KPHP) is not legally protected; 2) The 'Protected Peat Forest' scenario protects the HLG from conversion to other land use types; 3) The 'REALU' scenario reduces emissions from all land uses by protecting existing forests (HLG, BTNP, and ex-KPHP), and rubber and coffee agroforestry systems from conversion to other land use types. REALU also aims to support product diversification by maintaining local agroforestry practices, but excludes coconut agroforestry due to its much lower profit return relative to other livelihood options; and 4) The 'Green REALU' scenario is similar to the REALU scenario, though it restricts new oil palm plantations to non-productive non-peat soils such as grass or shrub lands only.

The simulated area was the Tanjabar district with a map resolution of 1 ha and a 5 km-wide buffer area around the district boundaries. The model simulations run for a duration of 30 years in order to show a complete cycle of an oil palm plantation, included as one of the main tree-based systems simulated in the landscape. The initial land cover and other input

Table 3 Four land use scenarios for FALLOW model simulation that determine the current and future of the rural landscape in Tanjung Jabung Barat, Jambi province

No	Scenario	Description	Remarks
1	Business as Usual (BAU)	• No protection for trees outside the Bukit Tigapuluh National Park (BTNP); for conversion into smallholder plots	• No new concession for oil, coal and natural gas exploration is assumed for 30-year simulation
		• Illegal conversion of protected peat forest (Hutan Lindung Gambut or HLG) into smallholder plots	• No change in road and settlement distribution and market price is assumed during 30-year simulation
		• Six types of tree-based system and 2 types of agricultural crops (Table 1) simulated as livelihood options for local people	
2	Protected Peat Forest	• Protection of the HLG	• Other conditions are the same as BAU
		• No protection for trees outside the legally protected forests (HLG and BTNP); for conversion into smallholder plots	
3	REALU	• Protection of rubber and coffee systems: no conversion is allowed to other livelihood options. Post-production rubber and coffee systems are rejuvenated	• Supporting low C emission development and product diversification
		• Protection for trees inside HLG, BTNP and ex-KPHP	• Other conditions are the same as BAU
4	Green REALU	Similar to REALU scenario, PLUS:	• Oil palm is introduced in shrub or grass lands to increase profitability and C stock in the lands
		• New oil palm plantations can only be established in non-productive non-peat soils (i.e. shrub or grass lands in non-peat soils)	
		• Post-production rubber production system (*Hevea brasiliensis*) are not rejuvenated, but are instead allowed to naturally develop into secondary forest	• Other conditions are the same as BAU

maps were taken from 2009. During simulations, no new concession of industrial timber or oil palm plantation or mining, and no change in road and settlement distribution over the landscape were simulated. The current version of FALLOW model does not simulate settlement development. A dynamic settlement, road or new plantation concession for example, needs an additional input map that describes its distribution in the future. Market price was assumed to be stable for all products across the years. The impacts of each scenario implementation on the ecological and economic levels are measured based on the observed standing C stock and profitability values, respectively (Table 2). In the simulations, smallholders will allocate more land and labour to those livelihood options that yield higher profits. Labour allocation to HTI and large scale oil palm plantation were not simulated due to lack of input data about labour requirement and income obtained from these off-farm jobs.

3 Results

3.1 Land cover output maps

In 2009, the peat areas in the Northeastern part of the landscape were dominated by coffee and coconut agroforests (Fig. 3a). Forests were still relatively abundant especially in the southwestern part, including the area of BTNP. The number of oil palm plots in non-peat soils was already significant and distributed among the young rubber agroforests. The large area of industrial plantation was, for the most part, not yet converted into acacia plantation. We assumed that a thorough conversion takes place in the fifth year of the simulation. The areas of rice and other annual crops were not significant and were scattered over the landscape.

In the BAU scenario, in the simulated land cover map of the year 2039, most of the coffee and coconut agroforests in the peat areas are replaced by new oil palm plantations (Fig. 3b). In non-peat soils, oil palm competes with rubber production system (*Hevea brasiliensis*) to dominate the landscape. The remaining peat forests (HLG) was thoroughly converted into new smallholder oil palm or coffee plantations.

In the Protected Peat Forest scenario, forests still exist, due to the protected status of peat forest in the upper part of the landscape, and in the national park in the lower part (Fig. 3c). Difficult topography also constrained forest conversions outside the national park, although the park maintains a relatively significant forest area in the southern part of the landscape. The final land use distribution in the BAU scenario is thus relatively similar to the protected peat forest scenario, except in the remaining peat forest area, where unprotected peat forests were converted to smallholder plantations.

In the REALU scenario, preventing the conversion of both existing and new coffee and rubber production system (*Hevea brasiliensis*) to other land use types produces significant area dominated by these two systems in the landscape (Fig. 3d). Coffee agroforests were maintained and developed in peat areas, while rubber agroforests mainly occurred in non-peat soils. In the Green REALU scenario, the areas of oil palm are not significant due to the limited area of shrub or grass lands available in the landscape (Fig. 3e). Consequently, rubber agroforests develop well in the non-peat soils.

3.2 Trade-off and compensation

The ecological and economic impacts of the simulated implementation of each scenario are represented relative to the BAU scenario (Fig. 4). All the scenarios result in lower per capita income relative to BAU. The negative trend in income from the BAU to Green REALU scenarios correlates with the percentage of oil palm area in the landscape (Table 4), thus indicating that income from oil palm plantations significantly affects income at the district level. On the other hand, higher C stocks were obtained, mainly through the conservation of larger forest areas (i.e. HLG, BTNP, and/or ex-KPHP as BTNP's buffer zone).

Great potential income loss was produced as an impact of preserving forests and agroforestry plots in the landscape (Table 5). A higher trade-off value was obtained when protecting rubber and coffee agroforestry systems and/or restricting new oil palm plantations in areas other than unproductive non-peat soils. This is because of the high potential loss in income from oil palm plantations. At the same time, C stocks in agroforestry systems are not higher than in oil palm plantations, except in comparison with the old rubber production system (*Hevea brasiliensis*). The higher C stock in the REALU and Green REALU scenarios mainly occurs because larger areas of forest are protected and there is no rejuvenation of old rubber production system (*Hevea brasiliensis*). As the scenarios studied did not involve change in areas allocated to the industrial timber plantations (HTI) and large scale oil palm plantation, ignoring income from these two options will not affect the trade-off calculation that measures relative income percapita between other scenarios and BAU.

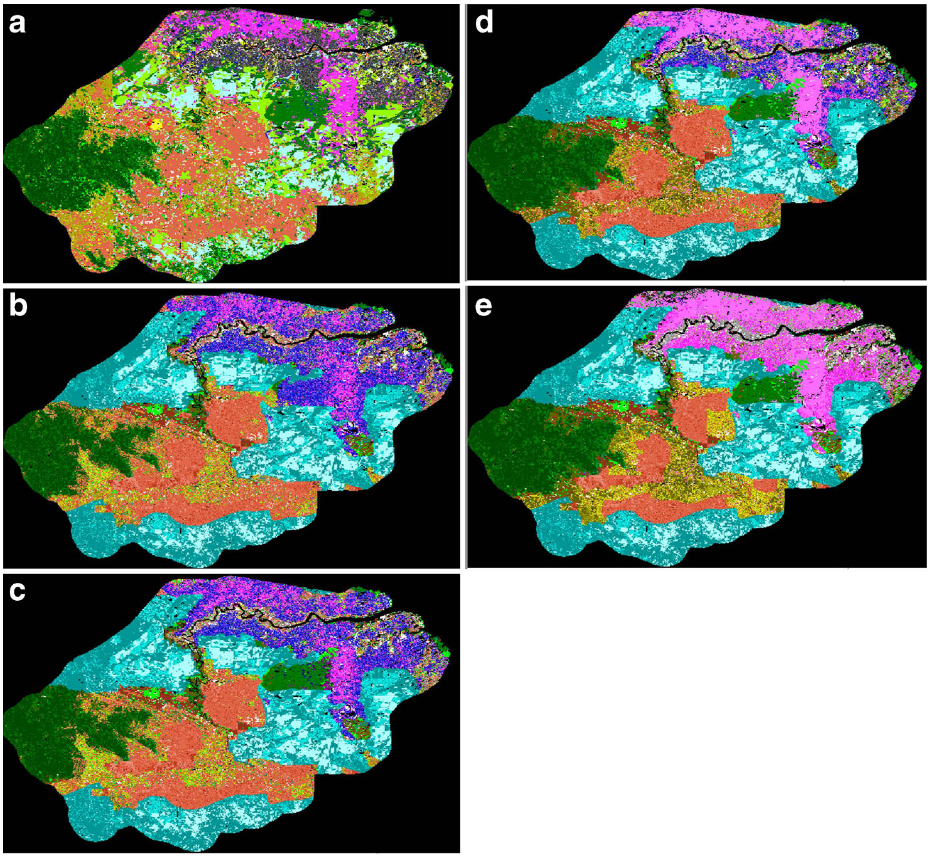

Fig. 3 Land cover map of 2009 (initial) according to the FALLOW model classification and output maps based on different scenarios at simulation year 30

4 Discussion

The implementation of land use scenarios that give priority to forest conservation or restoration usually produces trade-off that is negative in economic terms and positive on the ecological level when compared to scenarios that do not include conservation (Sunderland et al. 2008). In the Tanjabar district, the difference in C stock and income per capita between scenarios is mainly determined by how large forest areas are protected and which land use strategies are applied in peat areas. Restrictions on the establishment of new oil palm plantations and the preservation of local agroforestry practices are the key factors in producing the strong negative economic trends in the two REALU scenarios, relative to the BAU. In the Green REALU, the availability of non-productive non-peat soils, such as grasslands, for conversion into new oil palm plantations is too limited and cannot prevent significant loss in income. The calculation of the trade-off value here, however, does not take into account the prevention of belowground C stock emissions that prevail in all the scenarios other than the BAU. If these were taken into account, the calculated trade-off values are smaller than the presented values above. Based on the peat emission data from Agus et al. (2013), protecting the HLG from conversion into oil palm plantation will avoid

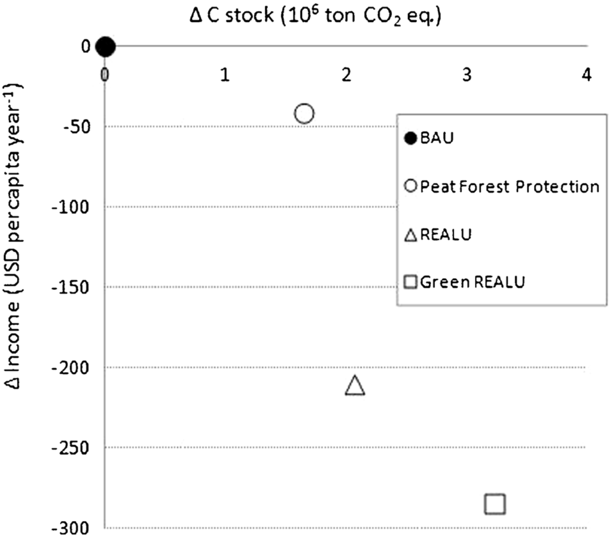

Fig. 4 Impact of each scenario application relative to the BAU scenario. Ecological impact is represented by standing C stock in the landscape (10^6 ton CO_2 eq.) and economic impact by income (USD per capita year^{-1}) measured as the average over the 30 year simulation

peat emission of around 0.23×10^6 ton CO_2 eq. year^{-1} if land conversion will not involve slash and burn practice; and as much as 1.76×10^6 ton CO_2 eq. year^{-1} with land clearance burning on peat soils. Including this peat emission in the calculation of trade-off value yields 5.4 USD ton^{-1} CO_2 eq. if the conversion did not involve slash and burn practice, and 2.9 USD ton^{-1} CO_2 eq. with that practice. The latter is much lower compared to the trade-off value that takes into account aboveground C stock only, i.e. 6.2 USD ton^{-1} CO_2 eq. (Table 5). For the two other interventions, the avoided peat emission because of agroforest protection and restriction of new oil palm plantation into underutilized mineral soils only are 0.058×10^6 ton^{-1} CO_2 eq. and 0.092×10^6 ton^{-1} CO_2 eq. respectively, as they would not affect the remaining peat forest. The new trade-off value for the two interventions are 86.41 USD ton^{-1} CO_2 eq. for agroforest protection and 14.53 USD ton^{-1} CO_2 eq. for oil palm

Table 4 Area of tree-based systems in the landscape of Tanjabar district, Jambi province, Sumatra Indonesia. Initial condition was measured in 2009. For the scenarios, the values represent an average over the 30 year simulation period with the FALLOW model

	Total area in the landscape (%)				
Tree-based system	Initial	BAU	Protected Peat Forest	REALU	Green REALU
Rubber agroforest	10.86	6.11	6.01	8.77	10.37
Coffee agroforest	7.55	6.80	6.46	9.89	14.02
Coconut agroforest	11.12	4.56	4.78	4.39	0.05
Total agroforest	29.53	17.47	17.25	23.05	24.44
Oil palm in peat	1.39	8.45	7.32	4.06	0.28
Oil palm in non-peat	19.45	20.06	19.34	16.82	14.42
Total oil palm	20.84	28.51	26.66	20.88	14.7

restriction. These are relatively close to those considering aboveground emission only (Table 5).

Similarly, the trade-off values could be much smaller if the FALLOW model took the economic valuation of other ecosystem services such as the richness of biodiversity, soil fertility, and/or watershed functions into account. Furthermore, product diversification through maintaining native agricultural practices can to some extent ensure the viability of smallholder incomes should the oil palm market weakens in the future.

A possible way to reduce potential income loss that results from the conservation programs is to receive compensation from potential donors. This relates to the compensatory system of rewarding the achievement of high levels of C storage and avoidance of C emissions, based on either an output or input approach (Tacconi 2009). The first option refers only to the C stock level, whereas the second relates to the efforts made to achieve that level. The high trade-off values in the two REALU scenarios, however, may preclude the possibility of obtaining full compensation from the C trading mechanism. Indeed, the application of any C compensation scheme is itself facing many challenges, such as the ongoing discussion regarding the most reliable methods of C stock measurement, payment mechanisms and related institutions, accountability, and accessing potential donors. Application of the fairness and equity principle among the multiple stakeholders involved at both the national and international levels is also important (Okereke and Dooley 2010). It is also crucial to take into consideration the value and provision of other environmental services, such as biodiversity levels or maintenance of water quality through the payment for environmental services mechanism. Despite facing implementation challenges that are similar to those of the C trading mechanism, recent studies by Jackson et al. (2010) and Lopa et al. (2012) indicate that the use of a solid framework that increases awareness and links multiple, mutually-benefiting partners is essential for successful and sustainable cooperation.

One intriguing possibility for Tanjabar is the effort to bring back the traditional practice of tapping Jelutung (*Dyera polyphylla*) in the district. This has potential to provide another significant source of income for local people, while still conserving and maintaining peat forest at the ecological level (RE-Peat). The latex serves as a non-timber peat forest product and the wood of old Jelutung trees can be used for various derivative products, such as plywood. The local district government is currently experimenting with the introduction of Jelutung intercropped between young oil palm trees in the plantations in peat areas. This experimental area may later serve as a demo-plot for the local people. Based on a rapid survey conducted in several villages in the district, around 20 % of local people expressed an

Table 5 Potential loss in annual income per ton C sequestration as an impact of scenario implementation in Tanjabar district, calculated by the FALLOW model

No	Intervention	Area (10^3 ha)	Δ population income (10^6 USD year^{-1})	Δ C stock in the landscape (10^6 t year^{-1})	Trade-off (USD ton^{-1} CO_2 eq.)
1	Protection of peat forest	15	−10.17	1.65	−6.17
2	Protection of rubber and coffee agroforestry	123	−41.35	0.42	−98.32
3	Oil palm restricted to unproductive non-peat soils	38	−18.21	1.16	−15.67
4	Total (1+2+3)	176	−69.73	3.23	−21.58

interest in converting their old oil palm plantations into monoculture Jelutung plantations (data not published). However, Sofiyuddin et al. (2012) estimated that Jelutung monoculture plantation in Tanjabar district might not be an efficient system. This is related to a positive cash flow obtained until after 10 years of management. A better management practice should be invented or Jelutung trees are kept as part of peat forest with its latex serves as a non-timber peat forest product.

From the ecological perspective, BAU represents a baseline or negative scenario, whereas the other options represent positive scenarios. The simulation results thus describe the range of possibilities that could occur and be encountered in the future by the relevant stakeholders in the district. Rather than waiting until one of the possible scenarios actually occurs, an appropriate response to the results of scenario analysis is to use the model outcomes to design the most sensible development strategy for implementation, which may include further exercises in emission reduction strategies and related activities. As with all other models, these model outcomes are sensitive to parameter values and assumptions and should not, therefore, be used as definite predictions. The scenarios studied here can be compared with those that emerge in land use planning tools for the area (Lusiana et al. 2013). By including more feedbacks and associated emission displacement (van Noordwijk et al. 2008), the dynamic model can refine initial estimates of the tradeoffs that derive from a simple comparison of land use systems and options (Tata et al. this issue).

The current version of FALLOW simply considers standing C stock as a representation of the ecological level and smallholder per capita income at the economic level. The next version has to take into account other environmental services such as biodiversity levels or water quality, and if possible translate these services into economic value. This could potentially result in a smaller discrepancy between conservation scenarios and profit-oriented scenarios at the economic level. Recently, the InVEST (Integrated Valuation of Environmental Services and Tradeoffs) model (Tallis et al. 2013) was developed to quantify and to map the values of environmental services. This model can be a good reference to design the next version of the FALLOW model.

5 Conclusions

It is very important to maintain forest and agroforests in the Tanjabar district not only for environmental functions but also for product diversification. The simulation with the FALLOW model suggests, however, that allowing condition as business as usual to prevail without a strict legal protection cannot hinder the conversion of the forests and agroforests to plantations. Relying on C compensation scheme is not a solution because of the high potential economic loss as an impact of implementation of conservation programs and restriction of new oil palm plantations. The seemingly feasible conservation strategy is to protect the remaining 15,000 ha peat forest which entails an opportunity cost of 6.2 USD ton^{-1} CO_2 eq. if the trade-off calculation involved aboveground emission only and 2.9 USD ton^{-1} CO_2 eq. if it included peat emission. The value will be lower if belowground sequestration of the peat forest is considered in the calculation. We conclude that the ways to provide options for maintaining the landscape of Tanjabar which sustain ecological and economic functions are through implementation of law-based protection of existing forests and/or agroforests, investment in intermediate intensity agroforestry options that utilize locally adapted trees and do not require drainage of peatlands, and efforts to bring back the traditional practice of tapping Jelutung latex as non-timber peat forest product.

Acknowledgments This scenario simulation using the FALLOW model was part of the REALU II project funded by NORAD (The Norwegian Agency for Development Cooperation). Input data for the model were collected by many colleagues working on this project whom the authors thank greatly. Constructive comments and feedbacks from two anonymous reviewers are highly appreciated.

References

Agus F, Henson IE, Sahardjo BH, Harris N, van Noordwijk M, Killeen TJ (2013) Review of emission factors for assessment of CO_2 emission from land use change to oil palm in Southeast Asia. In: Killeen TJ, Goon J (eds) Reports from the Science Panel of the Second RSPO GHG Working Group, Roundtable for Sustainable Palm Oil—RSPO, Kuala Lumpur, Malaysia

Bhagwat SA, Willis KJ (2008) Agroforestry as a solution to the oil-palm debate. Conserv Biol 22(6):1368–1370

Campbell-Smith G, Campbell-Smith M, Singleton I, Linkie M (2011) Apes in space: saving an imperilled orangutan population in Sumatra. PLoS One 6(2):e17210. doi:10.1371/journal.pone.0017210

Ekadinata A, van Noordwijk M, Dewi S, Minang PA (2010) Reducing emissions from deforestation, inside and outside the 'forest'. ASB Brief 16. World Agroforestry Centre, Nairobi

Jackson L, van Noordwijk M, Bengtsson J, Foster W, Lipper L, Pulleman M, Said M, Snaddon J, Vodouh R (2010) Biodiversity and agricultural sustainability: from assessment to adaptive management. Curr Opin Environ Sustain 1:1–8

Kartodihardjo H, Nugroho B, Putro HR (2011) Forest Management Unit (FMU): Concept, legislation and implementation. Ministry of Forestry, Jakarta

Khususiyah N, Janudianto, Mulyoutami E, Buana Y, Suyanto, Widayati A (2011) Livelihood options, poverty and equity in the peat and mineral lands of Jambi: case study in Tanjung Jabung Barat. In: Suyanto, van Noordwijk M (eds) REALU project report for Tanjung Jabung Barat (Tanjabar), Jambi, Indonesia. World Agroforestry Centre, Bogor

Koh LP, Ghazoul J (2010) Spatially explicit scenario analysis for reconciling agricultural expansion, forest protection, and carbon conservation in Indonesia. PNAS 107(24):11140–11144

Lee B, Meneghin B, Turner M, Hoekstra T (2003) An evaluation of landscape dynamic simulation models. USDA Forest Service, Washington

Lopa D, Mwanyoka I, Jambiya J, Massoud T, Harrison P, Ellis-Jones M, Blomley T, Leimona B, van Noordwijk M, Burgess ND (2012) Towards operational payments for water ecosystem services in Tanzania: a case study from the Uluguru Mountains. Fauna Flora Int Oryx 46(1):34–44

Lusiana B, van Noordwijk M, Cadisch G (2012) Land sparing or sharing? Exploring livestock fodder options in combination with land use zoning and consequences for livelihoods and net carbon stocks using the FALLOW model. Agric Ecosyst Environ 159:145–160

Lusiana B, van Noordwijk M, Johana F, Galudra G, Suyanto, Cadisch G (2013) Implication of uncertainty and scale in carbon emission estimates on locally appropriate designs to reduce emissions from deforestation and degradation (REDD+). Mitig Adapt Strateg Glob Change. doi:10.1007/s11027-013-9501-z

Messina JP, Walsh SJ (2001) Simulating land use and land cover dynamics in the Ecuadorian Amazon through cellular automata approaches and an integrated GIS. Open Meeting of the Human Dimensions of Global Environmental Change Research Community, Rio de Janeiro

Murray BC, McCarl BA, Lee HC (2004) Estimating leakage from forest carbon sequestration programs. Land Econ 80(1):109–124

Okereke C, Dooley K (2010) Principles of justice in proposals and policy approaches to avoided deforestation: towards a post-Kyoto climate agreement. Glob Environ Chang 20:82–95

Posa MRC, Wijedasa LS, Corlett RT (2011) Biodiversity and conservation of tropical peat swamp forests. BioScience 61(1):49–57

Rahayu S, Khasanah N, Asmawan T (2011) Above and belowground carbon stock. In: Widayati A, Suyanto, van Noordwijk M (eds) REALU project report for Tanjung Jabung Barat (Tanjabar), Jambi, Indonesia. World Agroforestry Centre, Bogor

Soares Filho BS, Rodrigues HO, Falieri A, Costa WL (2008) DINAMICA Ego Tutorial. Centro de Sensoriamento Remoto/Universidade Federal de Minas Gerais, Belo HorizonteBrazil

Sofiyuddin M, Rahmanulloh A, Suyanto (2012) Assessment of profitability of land use systems in Tanjung Jabung Barat district, Jambi province, Indonesia. Open J For 2(4):252–256

Sunderland TCH, Ehringhaus C, Campbell BM (2008) Conservation and development in tropical forest landscapes: a time to face the trade-offs? Environ Conserv 34(4):276–279

Suyamto DA, Mulia R, van Noordwijk M, Lusiana B (2009) FALLOW 2.0. Manual and Software. World Agroforestry Centre, Bogor

Tacconi L (2009) Compensated successful efforts for avoided deforestation vs. compensated reductions. Ecol Econ 68:2469–2472

Tallis HT, Ricketts T, Guerry AD, Wood SA, Sharp R, Nelson E, Ennaanay D, Wolny S, Olwero N, Vigerstol K, Pennington D, Mendoza G, Aukema J, Foster J, Forrest J, Cameron D, Arkema K, Lonsdorf E, Kennedy C, Verutes G, Kim CK, Guannel G, Papenfus M, Toft J, Marsik M, Bernhardt J, Griffin R (2013) InVEST 2.5.3 User's Guide. The Natural Capital Project, Stanford

van Noordwijk M (2002) Scaling trade-offs between crop productivity, carbon stocks and biodiversity in shifting cultivation landscape mosaics: the FALLOW model. Ecol Model 149:113–126

van Noordwijk M, Minang PA (2009) If we cannot define it, we cannot save it. ASB Policy Brief 15. World Agroforestry Centre, Nairobi, Kenya

van Noordwijk M, Suyamto DA, Lusiana B, Ekadinata A, Hairiah K (2008) Facilitating agroforestation of landscapes for sustainable benefits: tradeoffs between carbon stocks and local development benefits in Indonesia according to the FALLOW model. Agric Ecosyst Environ 126:98–112

van Noordwijk M, Minang PA, Dewi S, Hall J, Rantala S (2009) Reducing Emission from All Land Uses (REALU): The case for a whole landscape approach. ASB Policy Brief 13. World Agroforestry Centre, Nairobi, Kenya

Widayati A, Johana F, Zulkarnain MT (2011) Drivers of forest conversion and land use changes in the peatland of Jambi: historical analyses towards intervention for emission reduction. In: Widayati A, Suyanto, van Noordwijk M (eds) REALU project report for Tanjung Jabung Barat (Tanjabar), Jambi, Indonesia. World Agroforestry Centre, Bogor