The opportunity costs of emission reduction: a methodology and application to support land use planning for low emission development

S Suyanto, Andree Ekadinata, Rachmat Mulia, Feri Johana and Atiek Widayati

Highlights

- Opportunity cost, a basic concept from economic theory, informs decisions made by private land users and highlights social tradeoffs

- Quantifying social and private opportunity costs across landscapes is a powerful tool to assess the feasibility of reconciling conservation and development policy

- Opportunity cost analysis can help identify a fair compensation level for those who forego opportunities to change land use

- The REDD Abacus SP and FALLOW are complementary models that provide an effective means to identify possible conservation and development scenarios and to estimate associated opportunity costs

- Analytical models beyond opportunity costs should be developed to increase understanding of the total costs and benefits of land-based emission reduction activities

1. Introduction

Compensating landowners and countries for foregone benefits from development is at the heart of currently discussed mechanisms for Reducing Emissions from Deforestation and forest Degradation, preserving carbon stock, enhancing forest carbon stock and sustaining the management of forests (REDD+). For REDD+ efforts to achieve free, prior and informed consent, the level of compensation should be commensurate with the magnitude of negative economic consequences of not deforesting, not degrading, or actively protecting and enhancing carbon stocks. All land use choices have consequences for the expected future stream of costs and benefits to different stakeholders, which economists summarize in the concept of Net Present Value (NPV; see below). A choice for anything other than the most profitable land use implies an 'opportunity cost'. As it may also lead to a reduction of net emissions, we can express the ratio of difference in profitability and the gains in carbon as the minimum carbon price that would allow land users to break even when engaging in alternative emission reduction land use practices.

Defined as this ratio, the value of opportunity costs vary within and across landscapes, informing the design of efficient emission reduction programmes that want to maximize emissions reduction within a limited budget.

Opportunity cost is defined as the "…benefit forgone by using a resource for one purpose instead of another" (Maher et al., 2012). Opportunity cost is the value of the second best alternative, once all its implementation costs are accounted for. The opportunity costs from a private accounting perspective may differ from that of a societal (or social) perspective, as both costs and benefits are perceived differently. A difference between social and private opportunity costs can be the basis of a 'compensation' programme from which all involved can derive net benefits.

Pursuing emission reduction efforts under a landscape approach involves incorporating perspectives of multifunctionality as well as multiple actors and their stakes (van Noordwijk et al., 2011*a*). Use and utilization of lands provide a major entry point to a landscape approach when calculating emissions and in developing emission reduction strategies. Opportunity cost analysis can be an integral part of this process as it provides information of which land use(s) and which actor(s) are causing emissions, where the lost opportunities are if there is a change from a 'business as usual' scenario, as well as the associated gain for the next-best emission reduction option. These considerations of costs and benefits are translated into 'land use options' in the analyses, and reflect how the landscape will perform under different economic scenarios.

This chapter aims to contribute to the integration of opportunity cost analyses into emission reduction efforts to support land use planning for low emission development by discussing two methods and their applications. The chapter starts with a review of current theories and studies on opportunity costs and their contribution to emission reduction efforts. This is followed by descriptions of the two methods: REDD-Abacus SP and the FALLOW model. Application of these two methods is presented based on a case study in the Tanjung Jabung Barat (Tanjabar) District in Sumatra, Indonesia, in which the feasibility, scenario development and tradeoff analyses are incorporated and discussed. Finally, complementarities and limitations of the two methods are discussed.

2.   Integrating opportunity costs into emission reduction actions

Associated REDD+ costs have been grouped into three categories: 1) opportunity costs, 2) implementation cost, and 3) transaction costs (White & Minang, 2011). Among these three types of costs, the application of opportunity costs has been widely adopted for REDD+ feasibility studies (Potvin et al., 2008; UNREDD, 2011). According to Pagiola and Bosquet (2009), opportunity costs are usually the single-most important category of costs a country would incur if it reduced its rate of forest loss to secure REDD+ payments. Moreover, White and Minang (2011) argued that opportunity costs hold significant importance because they will 1) be the largest portion of costs associated with REDD+, 2) provide insight into the drivers of deforestation, 3) help to understand impact, and 4) help to identify fair compensation for those who change their land use to contribute towards emission reductions. Although, as we will discuss below, transaction and implementation costs for REDD+ may be higher than were originally envisaged, it will be the high opportunity costs that will directly indicate that REDD+ based on financial incentives is

unlikely to succeed in a given landscape, and it can thus act as a preliminary reality check and filter (van Noordwijk et al., 2011*b*).

The opportunity cost for avoiding deforestation can be calculated from the difference between the net benefit (NPV) provided by a land use that maintains forest and alternative land uses, such as agriculture. Data required for analysis of opportunity costs include a life cycle analysis of predominant land uses and their time-averaged carbon stocks, and quantified patterns of land use change (Hairiah et al., 2011). Based on review of 29 regional empirical studies, Bottcher et al. (2009) found the average opportunity cost was USD 2.51 per ton carbon dioxide equivalent (tCO$_2$e). Opportunity costs to reduce global deforestation by 46% based upon another study were estimated to range from USD 2.76 to USD 8.28/tCO$_2$e (Stern, 2007).

At the country and site level, Swallow et al. (2007) identified that a major opportunity for emission reductions, with modest opportunity costs, existed especially if forest conversion to three types of land-use could be avoided: 1) logging and subsequent conversion to extensive production of annual crops in sparsely-populated areas of Indonesia (East Kalimantan), Peru (Ucayali) and Cameroon (Awae); 2) conversion of forests to simple coffee systems in Lampung (Indonesia); and 3) all conversion of peat forests in Jambi province (Indonesia).While, in Sub-Saharan Africa, the main causes of forest conversion is still considered to be subsistence agricultural expansion and fuel extraction (Fisher et al., 2011), patterns in Latin America and Asia are dominated by production opportunities for domestic and export markets. The latter implies a likelihood of 'market-based leakage', as emissions avoided at one location are simply shifted elsewhere, as market demand remains unsatisfied (Kuik, 2014).

The Alternatives to Slash-and-Burn (ASB) Partnership has extended the scope of analysis to consider the inclusion of all sources of land-use based carbon pools and proposed the REALU (Reducing Emissions from All Land Uses) framework in this context. This framework consists of four pillars that reflect 1) the inclusion of emission reductions from deforestation and degradation (as in REDD), 2) emission reductions from peat lands, 3) enhancement of carbon sequestration and 4) emission reductions from agricultural activities (van Noordwijk et al., 2009).

Under the REALU framework, World Agroforestry Centre (ICRAF) has developed three opportunity cost methods (van Noordwijk et al., 2011*b*): 1) a direct comparison of NPV and time-averaged carbon stock at the level of land use systems as an easily applied first-level filter, 2) landscape-level opportunity cost curves using the REDD Abacus SP software, and 3) the FALLOW (Forest, Agroforest, Low-value Lands or Waste) model for further scenario analysis. We will here focus on the latter two methods.

3.   Opportunity cost methods

3.1   The opportunity cost curve using the REDD-Abacus SP software

The opportunity cost curve provides a comprehensive view on the relationship between opportunity costs and the volume of emissions that can be avoided in comparison to a business as usual scenario of land use change. The opportunity cost curve as such does not specify who will have to be paid how much to avoid (abate) emissions, but it does provide estimates of the average and marginal opportunity costs of emission reductions (Swallow et al., 2007). Figure 16.1 shows the schematic diagram of the calculation of opportunity costs.
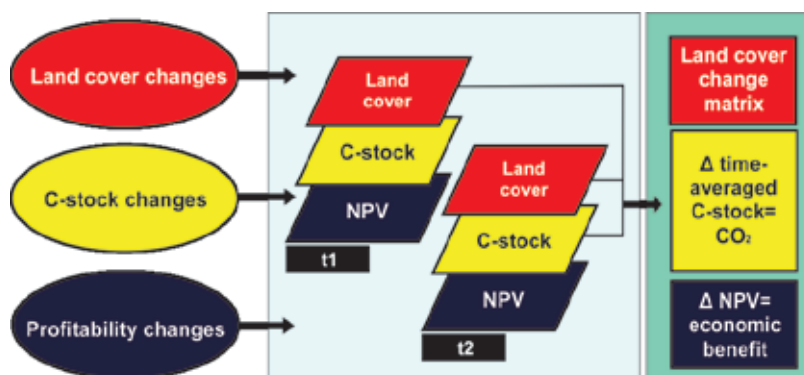
Figure 16.1 Schematic diagram of opportunity cost estimation (Swallow et al., 2007). C-stock = carbon stock.

The World Bank Institute adopted this opportunity cost curve method for estimating the opportunity cost of REDD+ (White & Minang, 2011). As part of this methodology, the REDD-Abacus SP software, developed by the World Agroforestry Centre (ICRAF; Harja et al., 2012), facilitates the calculations and construction of graphs. There are five steps in the analysis:

a. Land use classification and characterization

Selection of an operational land use classification for the focal area, that relates local land use typologies to remote sensing image analysis, characterized using life-cycle analysis to determine time-averaged carbon stock and profitability (White & Minang, 2011).

b. Analysis of land use, land use change and trajectories;

Analysis of land use and cover trajectory (ALUCT; Dewi & Ekadinata, 2010) requires a time series of land cover maps derived from satellite images. Knowing land use change patterns can identify drivers and agents of emitting-related activities in a particular period in the past. Two final forms of output resulting from ALUCT are: 1) area-based change analysis and 2) trajectory analysis. An area-based change analysis is a simple analysis conducted by comparing total area of land cover types in each time period. The results provide a clear indication of overall trends of land use/cover changes in the area. Maps can provide further information on the location and trajectories of changes. Trajectory analysis, when maps for more than two time-steps are available, summarizes sequences of historical changes in land use/cover of each pixel in the map within the study period.

c. Estimation of time-averaged carbon stock for the major land use systems

Aboveground carbon stock estimation is conducted through plot level measurement (Hairiah et al., 2009). Within a plot, the individual tree measurement is conducted measuring many variables for individual trees, including diameter at breast height and the species (or genus at the very least if species cannot be identified). Wood density is an important variable in estimating biomass, and therefore carbon stock (Chave, 2005), and a database developed by ICRAF can be used to access published literature at species or genus level to determine specific wood density. Additional field measurements include dead wood (necromass) measurement, litter data collection, and soil sample collection. Soil samples need to be analysed for the soil carbon content and the bulk density.

d. Calculation of the private profitability of the land use systems in terms of discounted net present value

A key summary metric of profitability of a land use system is the NPV (present discounted value) of revenues (volumes times price) less the costs of tradable inputs (e.g., fertilizer, fuel, etc.) and domestic factors of production (e.g., land, labour, management) over the specific time period considered in the analysis. The rental cost of land is typically not included because for a farmer or landowner the analysis considers the return to land. Because it can account for input and factor costs as well as outputs, and discounts future values over time, this measure of total factor productivity is superior to partial measures of productivity (e.g., yield or output per unit labour). Referring to Gittinger (1982), the NPV, i.e., the present worth of benefit (revenues) less the present worth of the cost of tradable inputs and domestic factors of productions, mathematically it is can be demonstrated by this equation:

$$NPV = \sum_{t=0}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Where B_t is benefit at year t, C_t is cost at year t, t is time denoting year and *i* is the discount rate.

The private profitability reflects a micro-economic perspective for farmer's decisions, comparing investment in alternative land use systems. The same costs and benefits calculated with the prices at the societal level (thus without the aggregated effects of taxes and subsidies), and with a discount rate reflecting choices in society, leads to the social opportunity cost, that should be applied to estimate net benefits for a national or regional economy as a whole (Kragten, 2001).

An investment in a land use activity unit over the period of analysis is appraised as profitable if NPV, adjusted for the opportunity costs of foregone options, is greater than 0. In reverse, an activity with NPV minus opportunity costs less than zero is 'unprofitable' by definition. Though this does not necessarily mean that there are no positive cash flows for such a system. Tomich et al. (1998) argued that in areas where land is scarce, the NPV calculation over a 25-year period can be interpreted as the 'returns to land' for the selected land use activity unit under study, because the returns are the 'surplus' remaining after accounting for costs of labour (including imputed value of family labour), capital (through discounting), and purchased inputs. Where the value of land changes in response to the land use practice, further adjustments will be needed.

It should be noted that the net stream of costs and benefits for a land use system that conserves or restores forest may well be negative if all local 'implementation costs' are included.

e. Developing the opportunity cost curve using the REDD-Abacus software

The opportunity cost of foregoing change of land use is the difference in NPV per tCO_2e emitted (Swallow et al., 2007). For each pair of changes in land use and land cover categories per unit area per year, changes of time-averaged carbon stock differences can be calculated. Correspondingly, the differences in NPV per unit area (can either be
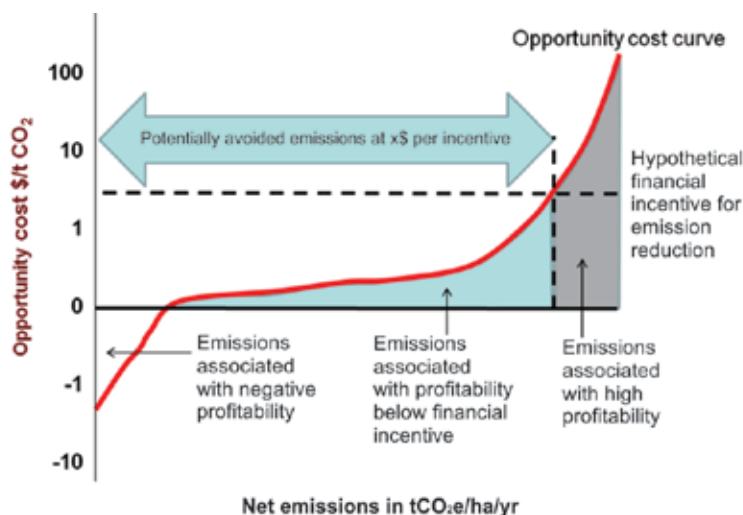
Figure 16.2 Conceptual figure of the opportunity cost curve (Swallow et al., 2007).

private or social profitability) can be calculated. Therefore changes in NPV per tCO_2e emitted can be calculated by dividing up changes in NPV with changes in carbon stock; the opportunity cost of the avoiding the particular changes in land use and land cover. Thus the formula to calculate the opportunity cost in USD/ tCO_2e is:

$$\frac{NPV_{Time\,2} - NPV_{Time1}}{3.67*(Cstock_{Time1} - Cstock_{Time\,2})}$$

Figure 16.2 shows a conceptual figure of an opportunity cost curve and its interpretation. Changes of time averaged carbon stock as a result of land use change is presented in the x-axis while change in profitability associated with the land use change is presented in the y-axis.

3.2   FALLOW (Forest, Agroforest, Low-value Lands Or Waste) model

FALLOW is a model that simulates the process of land use change. Instead of being based on a historical land use probability matrix to make projections of future land use like in REDD-Abacus, it regards farmers as the main agent of land use change. Their decisions, based on labour and capital allocation considerations for managing different land use types, determines the dynamic of the land use mosaic in a rural landscape. The model takes into account different factors that influence farmers' decisions including biophysical, economic, as well as social factors such as influence from relatives or openness to extension (van Noordwijk, 2002; Suyamto et al., 2009; Mulia et al., 2013*a*). The results of the simulation show the impact of land use changes on both economic and ecologic levels in the landscape.

Generally, a rural landscape consists of forest and non-forest lands (both of which can include smallholders) and large scale plantations. In large plantations, the type of vegetation is more fixed across the year. The main difference between the REDD-Abacus and the FALLOW model is thus the way they predict land use types in the smallholders' plantations.
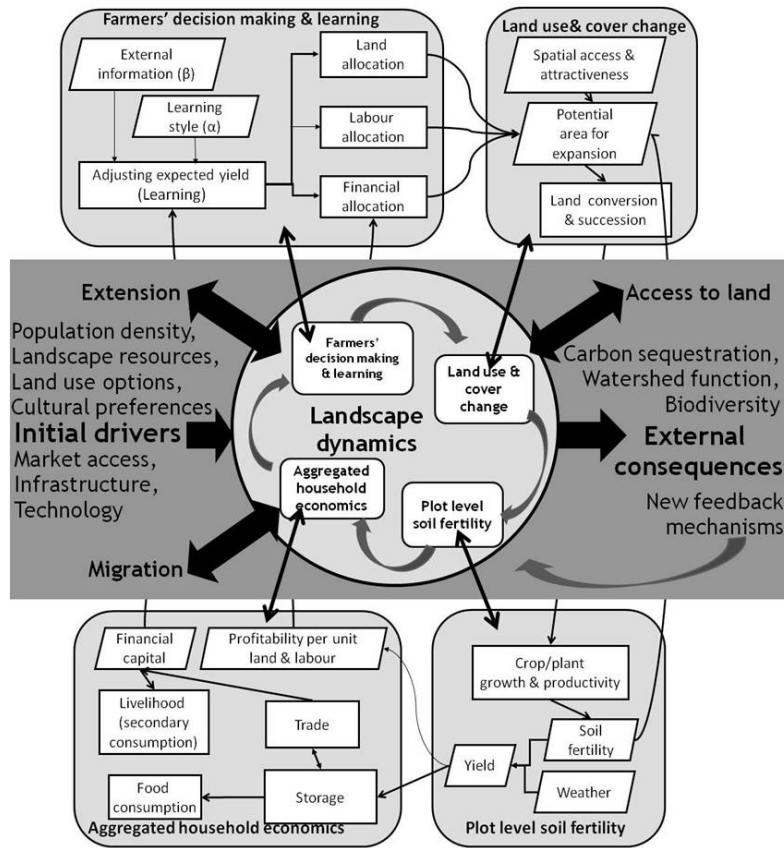
Figure 16.3 The four core modules of the FALLOW model described in Lusiana et al. (2012).

The FALLOW model is designed within the PC-Raster programming language. It operates in annual time steps and needs map-based inputs and parameter values. The input maps can be obtained from satellite images. Input maps and parameter values that represent biophysical, economical, demographic and social aspects in the landscape allow for the development of different land use strategies and scenario simulations within the model. In the current model version, economic and ecological dimensions in the landscape are represented by farmers' income per capita and by total standing carbon stock, respectively.

There are four core modules in the FALLOW model (Figure 16.3). They describe land use change as a result of the farmers' decisions and learning process about other land use options. The farmers consider current profit to labour and to land, cultural deliberation and external information (e.g., from relatives or extension) to determine land use types in the subsequent year. Available labour and land capital are allocated to selected land uses which later determine both spatial and temporal dynamics of the landscape mosaic. Land productivity depends on soil fertility and potential yield, where as income per capita is calculated based on income from the yields and/or off-farm activities. The calculated carbon stock in the landscape includes smallholders' plots and other land use types such as large plantations or forests.

4. Case study: the application of opportunity cost and FALLOW methodologies

An opportunity cost curve was estimated using the REDD Abacus SP software method to assess the economic feasibility of REDD+ in the Tanjabar District in Indonesia (Suyanto et al., 2014). In the same site the FALLOW model was used to calculate the potential cost needed to maintain local agroforestry and forest lands from the invasion of smallholder oil palm activities within the same district (Mulia et al., 2013*b*). The scale of analysis of the REDD ABACUS SP method can range from district to national level while FALLOW normally operates with input maps not more than 1 million pixels in size.
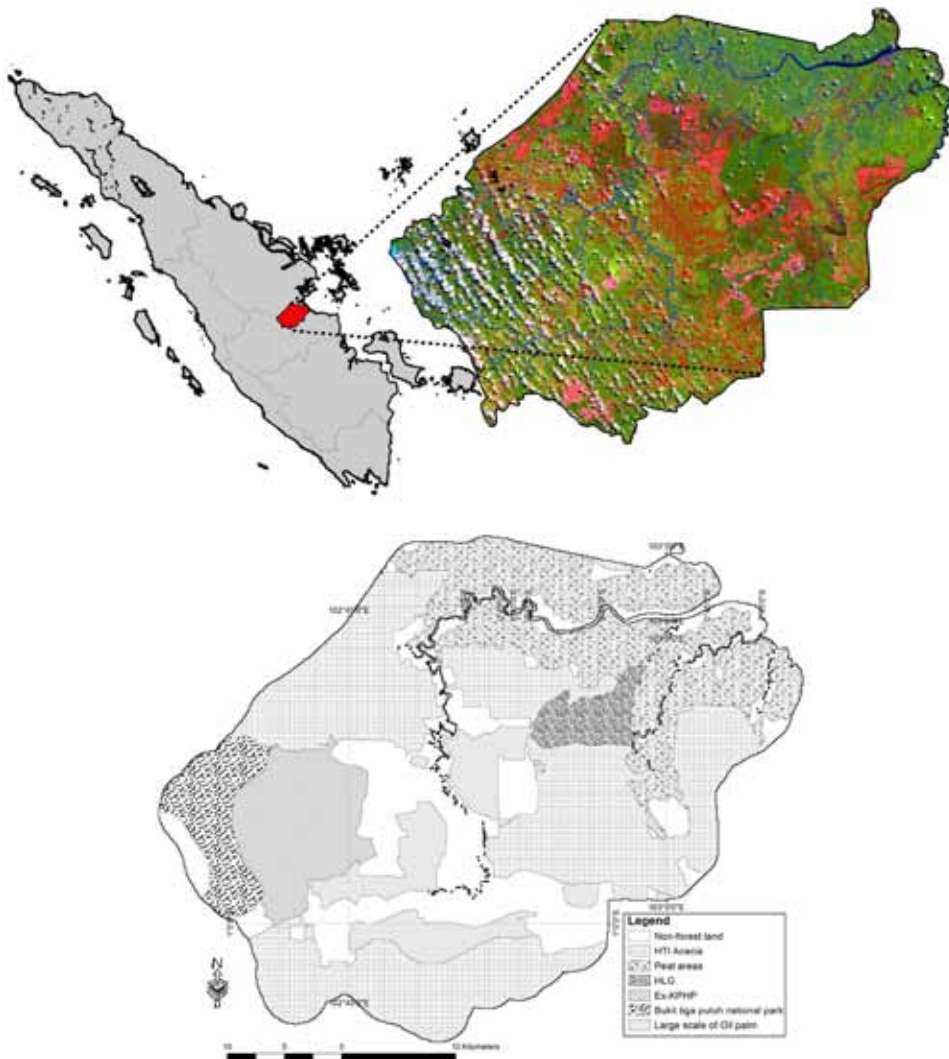
Figure 16.4 Location of Tanjabar District in Jambi Province, Sumatra, Indonesia and the different land uses within the landscape area.

The landscape of study in the district was made up a complex mosaic including a large portion of peat lands in the northern part of the district (Figure 16.4). The peat lands were mostly converted into smallholder plantations except an area called Hutan Lahan Gambut (HLG) that is now designated as protection forest for ecological and hydrological reasons. The remaining forests were situated mainly in the southern part of the district. An industrial timber plantation of acacia trees known as Hutan Tanaman Industri (HTI) covered about 35% of the district. Oil palm existed in both large plantations and smallholder plots. Important tree-based systems included rubber, coffee and coconut agroforestry systems with monoculture oil palm starting to gain more prominence within the district. The aim of the model's application was to calculate the potential cost needed to compensate farmers' income to incentivize them to maintain local agroforestry systems and remaining forests instead of converting their land into oil palm plantations, a highly profitable land use option in the region.

4.1   The feasibility for low-emission development in Tanjabar

Through intensive fieldwork in the landscape, time-averaged carbon stock and profitability for various land use systems were developed as shown in Table 16.1.

Table 16.1 Time-averaged carbon stock and profitability of land use systems in Tanjabar.

Land use system	Time average carbon stock (ton/ha)	NPV (USD/ha)
Rubber agroforest	58	1580
Rubber agroforest on peat	58	1481
Coffee-based agroforest	28	5722
Acacia plantation	58	1040
Rubber monoculture	41	2417
Rubber monoculture on peat	41	1747
Oil palm	40	7615
Oil palm on peat	39	5866
Coconut-betelnut agroforest	32	2002

Figure 16.5 shows the opportunity cost curve for Tanjabar in 2005-2009. The opportunity cost curve calculates potential avoided emissions through promotion of different land uses including the corresponding price of carbon needed as an incentive.

Figure 16.6 shows potential emission reductions in the district by 2020, assuming that all potential emissions with an opportunity cost below 5 and 10 USD can be avoided. The cumulative potential emissions in the district in 2020 is estimated at 61.91 tCO_2e/ha/yr, while the reduced emissions by excluding all land use conversion below a 5 USD threshold is estimated at 51.71 tCO_2e/ha/yr. The opportunity cost curved also showed that there is a potential for 16% emissions reduction using a 5 USD/tCO_2e incentive. However, if the threshold is increased to 10 USD, the amount of reduced emissions does not change much. For a large proportion of emissions in the landscape there are large opportunity costs making carbon payment incentive mechanisms prohibitive. This is a good example of

many areas in Indonesia where development activities, although producing a large amount of emissions, also are significantly profitability and important for local development. Therefore within the district a small amount of potential future emissions can be avoided through an incentive payment mechanism, but this should be complemented with policy interventions that focus on low-emission development strategies by conserving high carbon stock areas and focusing high carbon high profitability activity land development through participatory approaches such as land use planning.
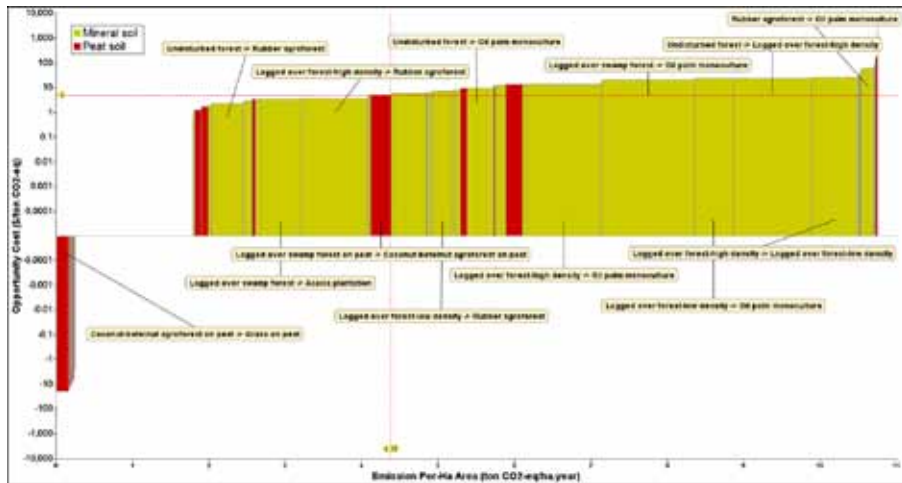

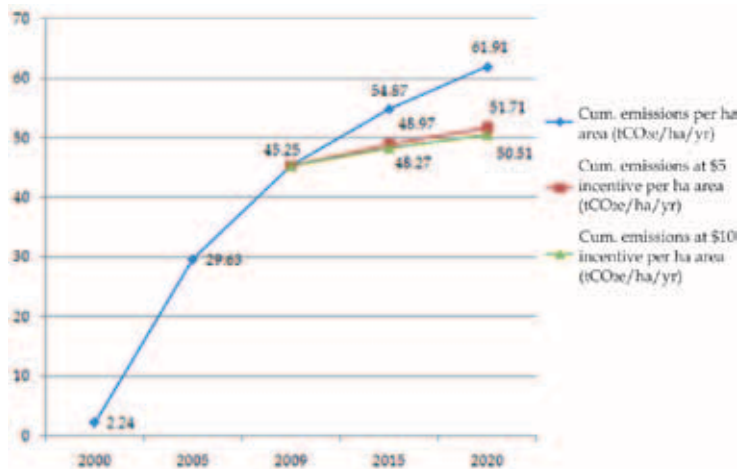**Figure 16.5** Opportunity cost curve of emission reductions from land use change in Tanjabar.

Figure 16.6 Potential emission reductions at 5 USD/tCO$_2$e and 10 USD/tCO$_2$e thresholds.

4.2   Scenarios to reduce emissions

Four land use scenarios were used in the FALLOW model (Table 16.2). They reflect possible emission reduction interventions as defined and described by different stakeholders in the Tanjabar District including the local forest and agricultural departments (Mulia et al., 2013*b*). 1) The current trend is reflected in the 'Business as Usual' (BAU) scenario where there is no protection of the remaining peat forest (HLG) for conversion into smallholder plots. The only protected forest is the Bukit Tiga Puluh National Park (BTNP) situated in the southern part of the district. No legal protection was granted for the rest of the forest on non-peat soils in the southern part. 2) In the second scenario, 'Protected Peat Forest', the HLG is protected from conversion to other land use types. 3) The 'REALU' scenario reduces emissions from all land uses through protection of existing forests and local agroforestry systems such as rubber and coffee from conversion to other land use types. This scenario also aims to support product diversification, but excludes coconut agroforestry due to its much lower profit return relative to other agricultural options. 4) The 'Green REALU' scenario is the REALU scenario plus restriction of new oil palm plantation establishment in non-productive, non-peat soils such as grass or shrub lands only.

In all scenarios, farmers are assumed to allocate land and labour capital proportionally to the profits gained in the simulated livelihood types. Due to lack of data about labour requirements, no labour was allocated to industrial acacia plantations (HTI) and large-scale oil palm plantations. Therefore, the calculated income per capita only includes income from smallholders' plantations outside the HTI, other large-scale plantations and protected forests. The calculated carbon stock, however, includes all land cover types in the landscape. The model ran for 30 simulation-years to cover a complete cycle of simulated tree-based systems. No change in road and settlement distribution was assumed in all scenarios. A simulation of dynamic road and settlement distribution in the landscape is possible when maps of future road and settlement distribution are provided as inputs to the model.

4.3   Tradeoffs between farmer income and emission reductions

Protecting the remaining 15 thousand hectares of HLG in the Protected Peat Forest scenario would require a tradeoff resulting in the potential loss of 10.7 million USD of farmers' income per year (compared to the BAU scenario; Table 16.2). On the other hand, the strategy can avoid the loss of 1.65 million tCO_2e/yr standing carbon stock resulting in a tradeoff value of about 1.76 USD/tCO_2e. A much greater potential loss of income resulted in the Green REALU scenario involving the preservation of forests and local agroforestry systems while restricting new oil palm plantations in areas other than unproductive non-peat soils as these restricted/protected activities encompassed a greater area. For the REALU scenario, only a slight difference in carbon stock was produced when preserving rubber and coffee agroforestry systems instead of allowing the plots to be converted into oil palm plantations due to the carbon stock of rubber and coffee systems not being higher than oil palm plantations with the exception of old rubber systems.

Table 16.2 Potential loss of annual income per tCO_2e of each scenario compared to the BAU in the Tanjabar District, calculated by the FALLOW model.

No	Intervention	Area (10^3 ha)	Δ total income (10^6 USD/yr)	Δ C stock in the landscape (10^6 tCO_2e/yr)	Tradeoff (USD/ tCO_2e)
1	Protected Peat Forest	15	-10.17	1.65	-1.76
2	REALU	123	-41.35	0.42	-26.82
3	Green REALU	38	-18.21	1.16	-4.27
4	Total (1+2+3)	176	-69.73	3.23	-5.88

5.   Complementarities and limitation of the methods

Although both the models discussed here, the REDD Abacus SP and FALLOW models, calculate opportunity costs, each have a slightly different focus. REDD Abacus SP focuses on the calculation of opportunity costs on all changed activities at the landscape scale and future scenario projections, while the FALLOW model is more focused on the benefits gained by the local community, for example, a farmer.

Like in all other models, the outputs of the two models are sensitive to the value of input parameters. Therefore, model parameterization should be done carefully not regarding the output values as exact values. Model outputs should be used as a basis to design a more sensible land use strategy to implement in the field.

The REDD Abacus SP is easier for implementation than the FALLOW model because it has less input parameters. However, this also means the model is less detailed in describing the process of land use change and its consequences. Still, the REDD-Abacus SP will have more groups of users because of its simplicity and quick preparation. On the other hand, due to much more input parameters to better understand the detailed process of land use change, the FALLOW model is suitable for those that aim to study the relationship between the process of land use change and the consequence to the people and the landscape. Still, albeit more complex, the FALLOW model only represents the ecological aspect in the landscape by standing carbon stock. In the current version, other aspects of ecological prosperity like biodiversity (included in the version used by van Noordwijk (2002)) or water quality are not taken into account.

REDD+ transaction and implementation costs need to be included in the overall decisions whether or not to engage in REDD+. The farm and landscape level implementation costs of forest protection or restoration should be included as NPV in a specific land use option. In current applications, however, the costs of active protection may be underestimated. Further implementation costs will be incurred when actual emission reductions have to be measured, reported and verified (MRV). Depending on the design of MRV systems, the temporal frequency and scale at which precision is needed (Lusiana et al., 2013) and the level of local involvement (Brofeldt et al., 2014), these MRV costs can exceed the opportunity costs. So far the transaction costs have been high in the early stages of the REDD Readiness learning curve (Agung et al., 2014), but are expected to sink into the background once REDD+ is implemented at the scale needed to achieve meaningful emission reductions.

6.   Conclusion

Assessing the opportunity costs through the two methods presented in this chapter has provided relevant information of forgone benefits given certain options of emission reductions pursued. The application of the two methods contributes equally at the broader landscape and administrative scale as well as at the net individual farmer level.

It is recognized that for emission reduction efforts, there are yet more relevant costs to be calculated. However, even with the absence of transaction costs, implementation costs and social costs, the analysis of opportunity costs can still be powerful in providing information for decisions-makers for assessing the economic feasibility of emission reductions from land use change or land-based activities.

Endnotes

1   http://www.worldagroforestry.org/regions/southeast_asia/resources/redd-abacus-sp
2   http://pcraster.geo.uu.nl

References

Agung, P., Galudra, G., van Noordwijk, M., & Maryani, R. (2014). Reform or reversal: the impact of REDD+ readiness on forest governance in Indonesia. *Climate Policy*. Retrieved from http://dx.doi.org/10.1080/14693062.2014.941317

Bottcher, H., Eisbrenner, K., Fritz, S., Kindermann, G., Kraxner, F., McCallum, I., & Obersteiner, M. (2009). An assessment of monitoring requirements and costs of "Reduced Emissions from Deforestation and Degradation". *Carbon Balance and Management*, 4, 7.

Brofeldt, S., Theilade, I., Burgess, N. D., Danielsen, F., Poulsen, M. K., Adrian, T, … Widayati, A. (2014). Community Monitoring of Carbon Stocks for REDD+: Does Accuracy and Cost Change over Time? *Forests*, 5, 1834-1854.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., … Yamakura, T. (2005).Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests. *Oecologia*, 145, 87–9.

Dewi, S., & Ekadinata, A. (2010). *Analysis of Land Use and Cover Trajectory (ALUCT)*. Bogor, Indonesia: World Agroforestry Centre - ICRAF, SEA Regional Office.

Fisher, B., Lewis, S. L., Burgess, N. D., Malimbwi, R. E., Munishi, P. K., Swetnam, R. D., … Balmford, A., (2011). Implementation and opportunity cost of reducing deforestation and forest degradation in Tanzania. *Nature Climate Change*, 1, 161-164.

Gittinger, J. P. (1982). *Economic Analysis of Agricultural Project* (2nd ed.). Baltimore, USA: John Hopkins University Press.

Harja, D., Dewi, S., van Noordwijk, M., Ekadinata, A., Rahmanulloh, A., & Johana, F. (2012). *REDD Abacus SP-User Manual and Software*. Bogor, Indonesia:World Agroforestry Centre-ICRAF, SEA Regional Office.

Hairiah, K., Dewi, S., Agus, F., Velarde, S. J., Ekadinata, A., Rahayu, S., & van Noordwijk, M. (2011). *Measuring Carbon Stocks across Land Use Systems: A Manual*. Bogor, Indonesia: World Agroforestry Centre - ICRAF, SEA Regional Office.

Kragten, M., Tomich, T. P., Vosti, S., & Goekowsi, J. (2001). *Evaluating land use systems from a socio-economic perspective*. Lecture note 8. Nairobi, Kenya: International Centre for Research in Agroforestry.

Kuik, O. (2014). REDD+ and international leakage via food and timber markets: a CGE analysis. *Mitigation and Adaptation Strategies for Global Change,* 19, 641-655.

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. *Agriculture, Ecosystem and Environment*, 159, 145–160.

Lusiana, B., van Noordwijk, M., Johana, F., Galudra, G., Suyanto, S., & Cadisch, G. (2013). Implication of uncertainty and scale in carbon emission estimates on locally appropriate designs to reduce emissions from deforestation and degradation (REDD+). *Mitigation and Adaptation Strategies for Global Change, 19*(6), 757-772.

Maher, M., Stickney, C., & Weil, R. (2011). *Managerial Accounting: An Introduction to Concept, Methods and Uses*. Mason, USA: South-Western, Cengage.

Mulia, R., Lusiana, B., & Suyamto, D. A. (2013*a*). *Manual of FALLOW Model Version 2.1*. Bogor, Indonesia: World Agroforestry Centre.

Mulia, R., Widayati, A., Suyanto, Agung, P., & Zulkarnain, M. T. (2013*b*). Low Carbon Emission Development Strategies for Jambi, Indonesia: Simulation and Trade-off Analysis Using the FALLOW Model. *Mitigation and Adaptation Strategies for Global Change,* 19,773-778. doi 10.1007/s11027-013-9485-8

Pagiola, S., & Bosquet, B. (2009). *Estimating the costs of REDD+ at country level.* Version 2.2. Arlington, VA: Forest Carbon Partnership Facility, World Bank.

Potvin, C., Guay, B., & Pedroni, L. (2008). Is reducing emissions from deforestation financially feasible?. A Panamanian case study. *Climate Policy*, 8, 23-40.

Suyamto, D. A., Mulia, R., van Noordwijk, M., & Lusiana, B. (2009). FALLOW 2.0. *Manual and Software*. Bogor, Indonesia: World Agroforestry Centre.

Suyanto, S., Ekadinata, A., Sofiyuddin, M., & Rahmanullah, A. (2014). Opportunity Costs of Emissions Caused by Land-Use Changes. *Open Journal of Forestry, 4*(1), 85-90.

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*, Cambridge, U.K.: Cambridge University Press.

Swallow, B., van Noordwijk, M., Dewi, S., Murdiyarso, D., White, D., Gockowski, J., ... Weise, S. (2007). *Opportunities for Avoided Deforestation with Sustainable Benefits. An Interim Report by the ASB Partnership for the Tropical Forest Margins.* Nairobi, Kenya: ASB Partnership for the Tropical Forest Margins.

Tomich, T. P., van Noordwijk, M., Budidarsono, S., Gillison, A., Kusumanto, T., Murdiyarso, D., Stolle, F., & Fagi, A. M. (Eds). (1998). *Alternatives to Slash-and-Burn in Indonesia: Summary Report and Synthesis of Phase II*. Bogor, Indonesia: ICRAF.

UNREDD (UN-REDD Programme Vietnam). (2011). *Final report: analysis of opportunity cost for REDD+*. Retrieved from http://vietnam-redd.org/Upload/Download/File/UN-REDD_OCA_Final_Report_3211_4432.pdf

van Noordwijk, M. (2002). Scaling Trade-offs Between Crop Productivity, Carbon Stocks and Biodiversity in Shifting Cultivation Landscape Mosaics: The FALLOW Model. *Ecological Modelling*, 149, 113–126.

van Noordwijk, M., Minang, P. A., Dewi, S., Hall, J., & Rantala, S. (2009). *Reducing Emissions from All Land Uses (REALU): The Case for a whole landscape approach.* ASB Policy Brief 13. Nairobi, Kenya: ASB Partnership for the Tropical Forest Margins.

van Noordwijk, M., Hoang, M. H., Neufeldt, H., Öborn, I., & Yatich, T. (Eds.) (2011*a*). How trees and people can co-adapt to climate change: reducing vulnerability through multifunctional agroforestry landscapes. Nairobi, Kenya: World Agroforestry Centre (ICRAF).

van Noordwijk, M., Dewi, S., Suyanto, Minang, P., White, D., Robiglio, V., … Harja, D. (2011*b*). *Abatement cost curves relating past greenhouse gas emissions to the economic gains they allowed.* Project Report. Bogor, Indonesia: World Agroforestry Centre - ICRAF, SEA Regional Office.

White, D., & Minang, P. (Eds.) (2011). *Estimating the opportunity costs of REDD+*. A training manual. Washington, DC: World Bank Institute.

Heterogeneous humid tropical landscape of Sumatra needs inclusive, integrated and informed land use planning. Photo credit: Degi Harja Asmara