Costs and Carbon Sequestration Assessment for REDD+ in Indonesia

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Abstract: Research Highlights: Our findings highlight that the contribution of carbon sequestration from plantations to REDD+ will remain limited, and that opportunity costs in Southeast Asia will likely increase, due to future oil palm expansion. Background and Objectives: Land use, land-use change, and forestry (LULUCF) are significant sources of carbon emissions. The United Nations Framework Convention on Climate Change (UNFCCC) agreed that the Reducing Emissions from Deforestation and Forest Degradation Plus program, also known as REDD+, could contribute to carbon sinks in tropical regions. These reductions could serve as carbon credits that offset emissions from other sources. Materials and Methods: This study uses the cellular automaton technique to simulate the business-as-usual (BAU) scenario and the gain-loss method, to measure carbon emissions resulting from forest conversion. The output of the integration of the models makes it possible to evaluate one of the most important financial costs: opportunity costs. Two scenarios (with and without consideration of carbon sequestration) in rubber and oil palm plantations are examined. Results: A sensitivity assessment in Kalimantan, Indonesia, shows that carbon sequestration from plantations affects value of opportunity costs less than social discount rates. Further analysis suggests that oil palm plantations have a greater impact than rubber plantations. Conclusions: Our study provides a case that can be applied to other regions for evaluating the impacts of plantation carbon sequestration, and insights that can help local policymakers design a financially attractive REDD+ program in other forest areas of the world.

Keywords: REDD+ program; opportunity costs; carbon sequestration

1. Introduction

Currently, climate change is one of the most urgent topics of global concern [1,2]. Climate change is caused by the effects of increased greenhouse gas emissions, such as carbon dioxide, due to anthropogenic activities [3–8]. Tropical rain forests play a key role in coping with the increase in global carbon dioxide levels [9], because tropical rainforest vegetation contains more carbon than the

mid-temperate zone and frigid zone forests [10,11]. At present, the carbon released by tropical rain forests due to deforestation accounts for 6%–15% of the annual global greenhouse gas emissions [12–15].

The 19th Conference of the Parties to the United Nations Framework Convention on Climate Change (COP19) and the 9th Conference of the Parties to the Kyoto Protocol (CMP9) were jointly held on the topic of Reducing Emissions from Deforestation and Forest Degradation Plus (REDD+) funding in Warsaw, Poland, from 11–22 November 2013. In-depth discussions on the action points, coordination of REDD+ action support, and land use, land-use change, and forestry -related technical issues were held [16–18]. In 2016, the central role of forests to meet the well below 2 °C goal through mitigation from REDD+ action was recognized by Article 5 of the Paris Agreement [19,20]. Most recently, developing country Parties implementing REDD+ activities are encouraged to complete the Warsaw Framework for REDD+, with online safeguards information systems and submissions of summaries of information to the UNFCCC (REDD monitor, 2020) [21].

Deforestation and forest degradation monitoring, reporting and verification, determination of the carbon emission reference levels (baselines), the National Forest Monitoring System (NFMS), the Forest Reference Emission Level and Forest Reference Level (FREL/FRL), the Strategic Environmental and Social Assessment (SESA), REDD+ Strategy are basic issues for REDD+ [22,23]. The goal of REDD+ is to raise funds from developed countries to help developing countries reduce emissions caused by deforestation. Its core principle involves using market mechanisms to encourage reduction of the greenhouse gas emissions caused by deforestation, by reducing forest damage and preventing forest degradation, while allowing these countries to obtain corresponding income through the carbon market [24–28].

Nowadays, cocoa, coffee, tea, coconut, bananas, rubber, and oil palm are the most valuable plantations in tropical regions [29]. Financial costs play a key role in REDD+. The IPCC AR5 performed a detailed analysis of global and regional costs associated with REDD+. This analysis demonstrated that forestry-related emission mitigation represents a cost-effective mechanism and, furthermore, produces other benefits [1]. Despite these benefits and the substantial progress of REDD+, costs are one of unresolved fundamental issues [30–32]. Opportunity costs (OC) are one of the major costs in the application of REDD+. OC could be defined as the net income divided by the net carbon emissions avoided per hectare. By disregarding the existence of and circumstances surrounding weak property rights and limited control over land use in many tropical forests, deforestation actors command their resources in any manner they see fit to gain financial (or other) benefits [26]. In the REDD+ program, policymakers establish an incentive payment or a payment for ecosystem service (PES) scheme, thereby rewarding actors with carbon credits for reducing emissions related to deforestation and forest degradation below a given threshold. Whether actors cut forests down is determined by the revenue gap between net present values (NPV) from composite commodities and perceived REDD+ payments for actors. In this way, deforestation is positively related to income associated with timber sales and agricultural activities, and negatively related to REDD+ payments. Alternatively, lower levels of deforestation result in reduced income from composite commodities, but higher revenues from the REDD+ program [27].

Farmers should be compensated for their losses of opportunity costs from stopping deforestation activities. OC can serve to indicate the minimum amount that would need to be paid to forest owners to keep them from engaging in deforestation [33]. In contrast, in places with the potential for development of high-value economic activities, REDD+ activities may only make sense as an incremental incentive in forest conservation. In addition, investments towards improving forest governance and regulation, or recognizing customary land rights, can be a cheaper option for protecting natural forests [34]. Gregersen et al [18] indicate that OC may distort the real costs of REDD+. These distortions are caused by the fact that: (i) OC may not be an appropriate indicator for measuring the true costs of stopping deforestation; (ii) OC may not be sufficient to explain the payment required to stop deforestation; (iii) in a system with poor market operation, estimation of OC is difficult; and (iv) in the case of the

continuous development of the main carbon offset market, the price paid to forest land owners for non-deforestation is determined by the market.

One of the factors in OC is the discount rate. The choice of the discount rate depends on various factors, like whether a country is developed or developing. Smith indicated that since REDD+ implementation is for a long period of time a social discount rate could better reflect its feature of non-marginal policy [35]. For example, the major assessments of climate change policies, the Stern Review and the Garnaut Review, usually used the social discount rates, rather than a market rate [36,37].

As the first and second in production in the world, oil palm plantations in Indonesia and Malaysia are major cause of the massive destruction of tropical forests, since they generate about USD 10 billion in exports [38,39]. For example, due to palm oil plantation expansion, the current forest cover in Kalimantan of Indonesia declined from 75% in the mid-1980s, with an annual deforestation rate of 1.3 million ha. As a result, Kalimantan suffered the highest rate of deforestation in Indonesia [40,41]. The drivers of such large-scale of deforestation are economic, social, and especially from the decentralization policy implemented in Indonesia since 2000.

There is long standing debate on the appropriate scale and intensity for carbon sequestration in these agroecosystems in these two countries. For example, the GHG inventory in the Second National Communication by the Ministry of Natural Resources and Environment Malaysia [25] showed that, in 2007, oil palm plantations and forests were the two primary CO_2 removers for Malaysia. The prior studies of the OC for REDD+ mainly concentrate on costs assessment. However, few studies focus on the carbon sequestration impact from the agroecosystems on OC, which is important to understand the payment barriers, potential trade-offs between environment and development, and the possible co-benefits that can be achieved within a successful REDD+ implementation. Since OC is defined as the net income divided by the net carbon emissions avoided per hectare, the carbon sequestration from these plantations has potential impact on OC of avoided deforestation which could be compensated by REDD+ payment. For this purpose, we developed a spatially explicit modelling framework to capture reasonable payments under two scenarios that reflect concerns about carbon sequestration in plantations: (1) Scenario A: without consideration of carbon sequestration in plantations, and (2) Scenario B: with consideration of carbon sequestration in plantations. We conducted a case study on Kalimantan, Indonesia, and focused on two major types of plantations: oil palm and rubber plantations.

2. Materials and Methods

2.1. Study Area

The study area (Figure 1) is 22.5 km × 21.5 km (47,940.75 hectares) at north Palangka Raya in Central Kalimantan, Indonesia. This area has historically been surrounded by heath forests and peat swamps, but has experienced deforestation since 2000. The study by Kanninen et al. [42] showed that, in the next 30 years, the clearing rate of the forests in this area could reach the highest level.
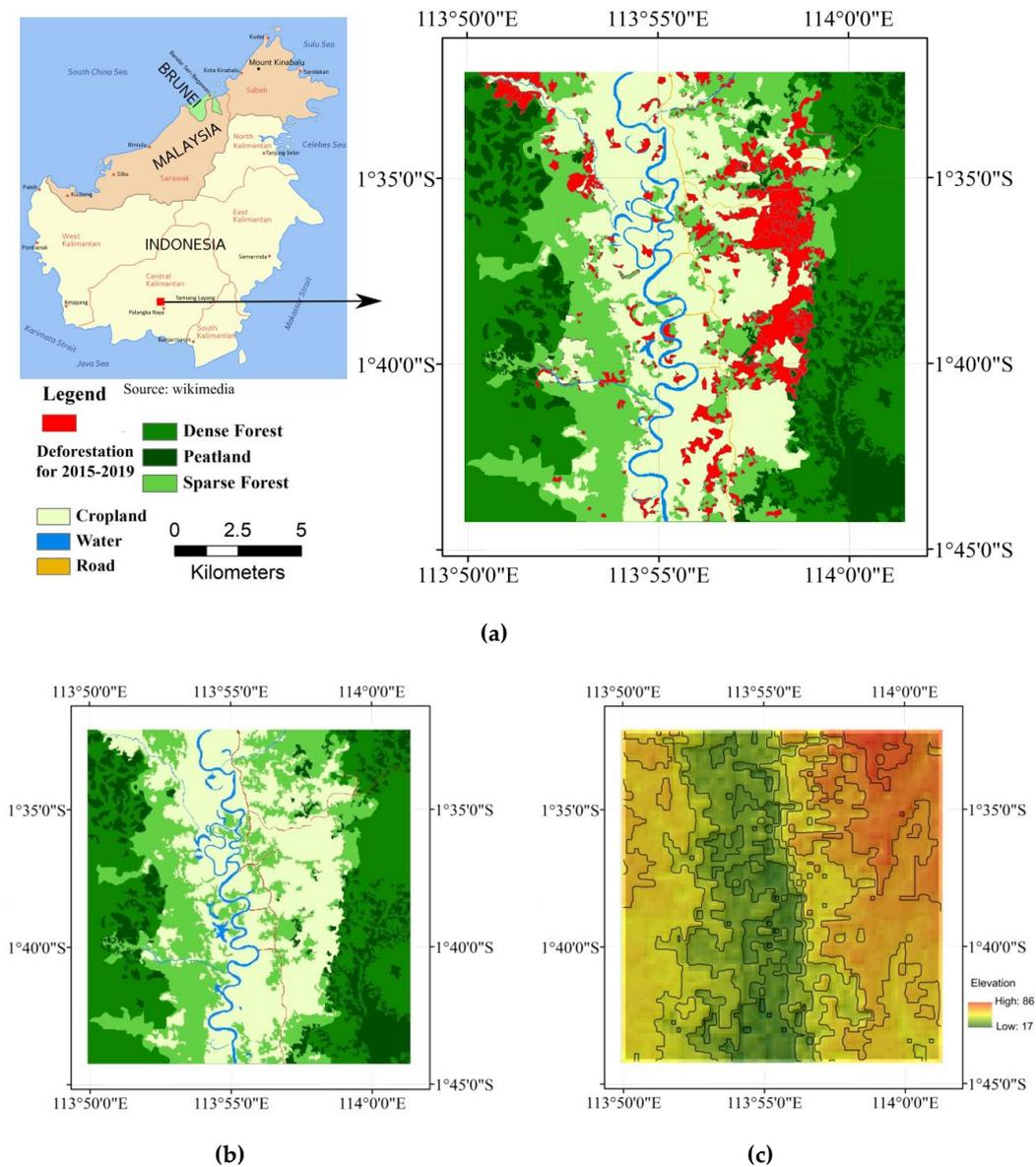
Figure 1. (**a**) Deforestation map, (**b**) land use map, and (**c**) topography in the study area.

2.2. Data Description and Processing

Taking into account the availability of the data and their matching, this study used the Enhanced Thematic Mapper Plus/Thematic Mapper (ETM+/TM) remote sensing images in the study area, to interpret land use changes. The band combination technique is helpful for distinguishing different vegetation types when supplemented by NDVI data. Supervised classification was performed using the selected training samples to obtain the classification results. In this method, we first generated representative parameters in known areas for each land use class of dense forest, peatland, sparse forest, cropland, road, and water. We then checked and compared spectral characteristics for these classes to ensure the distinction. Finally, the maximum likelihood classification (MLC) technique, which assumes that the statistics for each class in each band can be described by a multivariate normal distribution and calculates the probability that a given pixel belongs to a specific class [43], was used, to perform classification via all the bands of the data. FAO [44] indicated that changes from dense forest, peatland, and sparse forest could be regarded as "deforestation".

OC could be calculated using the following formula:

$$OC^{BAU} = \frac{P_t^{FC}}{C_t^{FC}}$$

(1)

where OC^{BAU} is opportunity costs, measured as the revenues gained per tonne of CO_2 emissions avoided under business-as-usual (BAU) conditions (expressed in USD/tCO$_2$); $P_t{}^{FC}$ represents the net revenues (revenues minus costs) gained from a composite commodity after a forest is converted to land amenable to plantations (expressed in USD); and $C_t{}^{FC}$ stands for total emissions produced from converting a forest (expressed in tonneCO$_2$).

As a composite variable, $P_t{}^{FC}$ is the net present value (NPV) generated from harvesting one hectare of forest. This composite variable can be modelled as:

$$P_t^{FC} = P_h^{FC}(t) + \sum_{i=1}^{N} \int_0^T \theta_i \times A_i(t)e^{-\varphi t}dt = P_h^{FC} + \sum_{i=1}^{N} \int_0^T \theta_i \times (R_i(t) - C_i(t))e^{-\varphi t}dt$$

(2)

where $P_h{}^{FC}(t)$ is the one-time timber harvest value at time *t*; $A_i(t)$ is the annual net revenue of the ith agricultural activity permitted by the land conversion at time *t*; $R_i(t)$ is the annual revenue of the ith agricultural activity permitted by the land conversion at time *t*. $C_i(t)$ is the annual costs of the ith agricultural activity permitted by the land conversion at time *t*. *T* denotes the period over which the forest is protected (expressed in years). For the expression $\psi = \ln(1+\gamma)$, γ is the discount rate. Finally, θ_i is the ratio of ith agricultural activity area to the total area.

Due to the limitation of the resolution of the satellite sensors, we conducted field surveys to reveal the ratio of plantation area. By visiting 189 randomly chosen households, we found that the average of oil palm plantation area and rubber plantation area is about 51% and 32.7% of the total, respectively. In the study from Yamamoto and Takeuchi [45] it was found that oil palm plantations and rubber plantation produce yield by the 3rd year and the 11th year, respectively. Plantation costs are USD 830 per hectare, when considering logging revenue and worker wages.

In order to set emission reduction targets, a reference level, which reflects what would have happened in the absence of REDD+, and thus quantifies the mitigation impact of a project or policy, must be developed. Using a reference level, reductions in emissions can be measured and credited, allowing for the provision of compensation. Bond et al. [17] indicated three approaches to determining the reference level: (i) extrapolating existing or historical rates of deforestation, also called BAU; (ii) estimating changes in carbon stocks from economically attractive land use options, taking into account barriers to investment; and (iii) estimating changes in carbon stocks from the most likely land use at the beginning of the project. This study used the cellular automata model to simulate the BAU related to land use development and changes [28]. The cellular automaton model, which is comprised of four elements and one important condition, can be expressed as follows:

$$BAU^{CA} = \{X, S, N, R\} \cup DR = \frac{1}{t_2 - t_1} \times \ln\left(\frac{DA_2}{DA_1}\right)$$

(3)

where *BAU* represents spatial pattern of land use change under business as usual; *X* represents the individual land use cell; *S* indicates how the land is being used as per REDD+; *N* is the cell neighbourhood, which represents the attraction (positive) and repulsion (negative) effects of the various land use cells; *DR* indicates the rate of deforestation, which can be calculated using the compound interest law [46]; DA_1 indicates forest area (in hectares) at t_1; and DA_2 indicates forest area (in hectares) at t_2.

N is obtained as:

$$N_i = \sum_x \sum_d W_{sxd} I_{xd}$$

(4)

where *Wsxd* is the weighting parameter applied to states *S* at position *x* in distance zone *d* of the neighbourhood; I_{xd} is the Dirac delta function, which equals 1 if the cell is occupied by state *S*, and 0 otherwise; and *R* indicates the transition rules that represent a vector of transition potentials for each cell from N_i:

$$R_i = P\{j \Rightarrow k | N_1 \cap N_2 \cdots \cap N_i\} = e^{\sum W_i^+} / \left(1 + e^{\sum W_i^+}\right) \tag{5}$$

where W+ is the weight of evidence, which can be calculated as:

$$\log\{D | N_i\} = \log(D) + W^+ \tag{6}$$

where *D* is the event.

There are two methods to estimate carbon emissions in IPCC guidelines: gain-loss method and stock-difference method [47]. Gain-loss method considers all carbon gains processes (e.g., growth) and all carbon losses processes (e.g., clearing, fires, decay et. al.), and, thus, is used to measure forest conversion emissions in this study. Forest emissions can be estimated as [48]:

$$C_t^{FC} = \int_1^T C_{f,net}^{FC}(t)dt = \int_1^T (C_{f,burn}^{FC}(t) + \int_{f,decay}^{FC}(t) + C_{f,plantations}^{FC}(t))dt \tag{7}$$

where $C_{f,net}{}^{FC}(t)$ is total flux from forest conversion; $C_{f,burn}{}^{FC}(t)$ is burnt flux; $C_{f,decay}{}^{FC}(t)$ is the fluxes of carbon from decay; and $C_{f,plantations}{}^{FC}(t)$ is carbon flux from uptake from plantations. They are expressed in tC/yr.

Following Ramankutty's work [30] burnt flux is calculated as:

$$C_{f,burn}^{FC}(t) = Bio_{clear}(t) \times 0.2 \tag{8}$$

where $Bio_{clear}(t)$ is the total biomass from deforestation and the biomass from cleared secondary vegetation (expressed in tC/yr). This can be calculated with the following formula:

$$Bio_{clear}(t) = Bio_{defore}(t) + Bio_{SFclear}(t) \tag{9}$$

where $Bio_{SFclear}(t)$ is:

$$Bio_{SFclear}(t) = \int_1^t C_{SF}(\tau) \times A_{SF,clear}(t,\tau)d\tau = \int_1^t C_{veg} \times 0.7 \times \tau/T \times A_{SF,clear}(t,\tau)d\tau \tag{10}$$

and $A_{SF}(t,\tau)$ represents the area of secondary forest for age-cohort τ at time t [30].

The following differential equation represents carbon fluxes from the slash, product, and elemental pools:

$$\frac{dC}{dt} = C_{in} - \lambda C \tag{11}$$

where C_{in} is the transfer of carbon from deforestation, and λ is the decay rate. The respective carbon dynamics for the various pools can be calculated using:

$$C_{slash}(t) = (1 - \lambda_{slash}) \times C_{slash}(t-1) + C_{in,slash}(t) \tag{12}$$

$$C_{prod}(t) = \left(1 - \lambda_{prod}\right) \times C_{prod}(t-1) + C_{in,prod}(t) \tag{13}$$

$$C_{ellm}(t) = (1 - \lambda_{ellm}) \times C_{ellm}(t-1) + C_{in,ellm}(t) \tag{14}$$

and the fluxes of carbon from the decay of these pools are calculated as:

$$C_{f,decay}^{FC}(t) = \lambda_{slash}C_{slash}(t-1) + \lambda_{prod}C_{prod}(t-1) + \lambda_{elem}C_{elem(t-1)} \tag{15}$$

where $\lambda_{slash} = 0.1$, $\lambda_{prod} = 0.1$, and $\lambda_{elem} = 0.001$ [30].

Over the course of period *T*, the carbon flux from uptake from plantations is:

$$C^{FC}_{f,plantation}(t) = \sum_{i=1}^{N} \theta_i \times C^{FC}_{f,i}(t) \tag{16}$$

where θ_i is the ratio of ith agricultural activity area to the total area.

The values from in situ forest inventories from Rahajoe [49] were the values of biomass. The studies on rubber plantations from Wauters et al. [50] and oil palm plantation from Khasanah et al. [51] were used to obtain carbon stocks for rubber and oil palm, respectively. The parameters for carbon pools from Ramankutty et al [48] were used in Equation (7)–Equation (16). A field survey revealed that most forests in the study area were mature forests. It is common practice under REDD+ to exclude this marginal benefit of retaining forests, so we ignore carbon sequestration from the remaining forest area.

To identify how significant any given input variable is in determining a project's worth, or to reveal which parameter is more important on the results when we change input values, we conducted sensitivity analyze in this study. Sensitivity analysis is calculated as following [52]:

$$S = (dx/x)/(dp/p) \tag{17}$$

where *S* is sensitivity, *x* is state variable (e.g., OC), *p* is parameter (e.g., discount rates or plantation area), *dx* and *dp* are change of values of state variables and parameters.

Grieg-Gran indicated that 10% was the most common discount rate used in REDD+ studies for OC [53]. As a result, in this study a discount rate of 10% was used as a base case, to compare costs incurred at different points in the future to costs incurred today based on the normative approach. For a sensitivity analysis that determines model robustness, we calculate the OC using lower social discount rates of 2.5% and 5%, and higher social discount rates of 10% and 15% under the two scenarios.

3. Results and Discussion

3.1. Land Use Changes

The land use maps show that forested areas (dense forest, peatland, and sparse forest) declined from 61.5% in 2005 to 54.6% in 2009, indicating an average annual loss of 2.31% of the forest area. This loss in forest area occurred in parallel with an increase of 3.15×10^3 hectares in the farming and plantation area, and a small increase in the number of roads, indicating that farming and plantations were the primary drivers of deforestation. In the business-as-usual (BAU) simulations, we tested a set of physical parameters as factors that affect changes in land use. These parameters include aspect, elevation, slope, soil type, distance to previously deforested land, distance to rivers, distance to roads, and distance to villages. After comparing the simulation results with an actual land-use map, we calculated a Kappa coefficient of 0.65.

3.2. Carbon Emissions and Net Present Values

Figure 2 illustrates carbon emissions by predicting future land use changes under two scenarios. Deforestation reduction in the east of the study area is disproportionately important to achieve REDD+ emission reduction targets due to paired high risks and high carbon stocks. Wilson, K. A et.al. [54] indicated that such hotspots with vulnerability to deforestation should be well identified, mapped, and characterized to help improve the planning of budgets and conservation plans for REDD+ implementation.
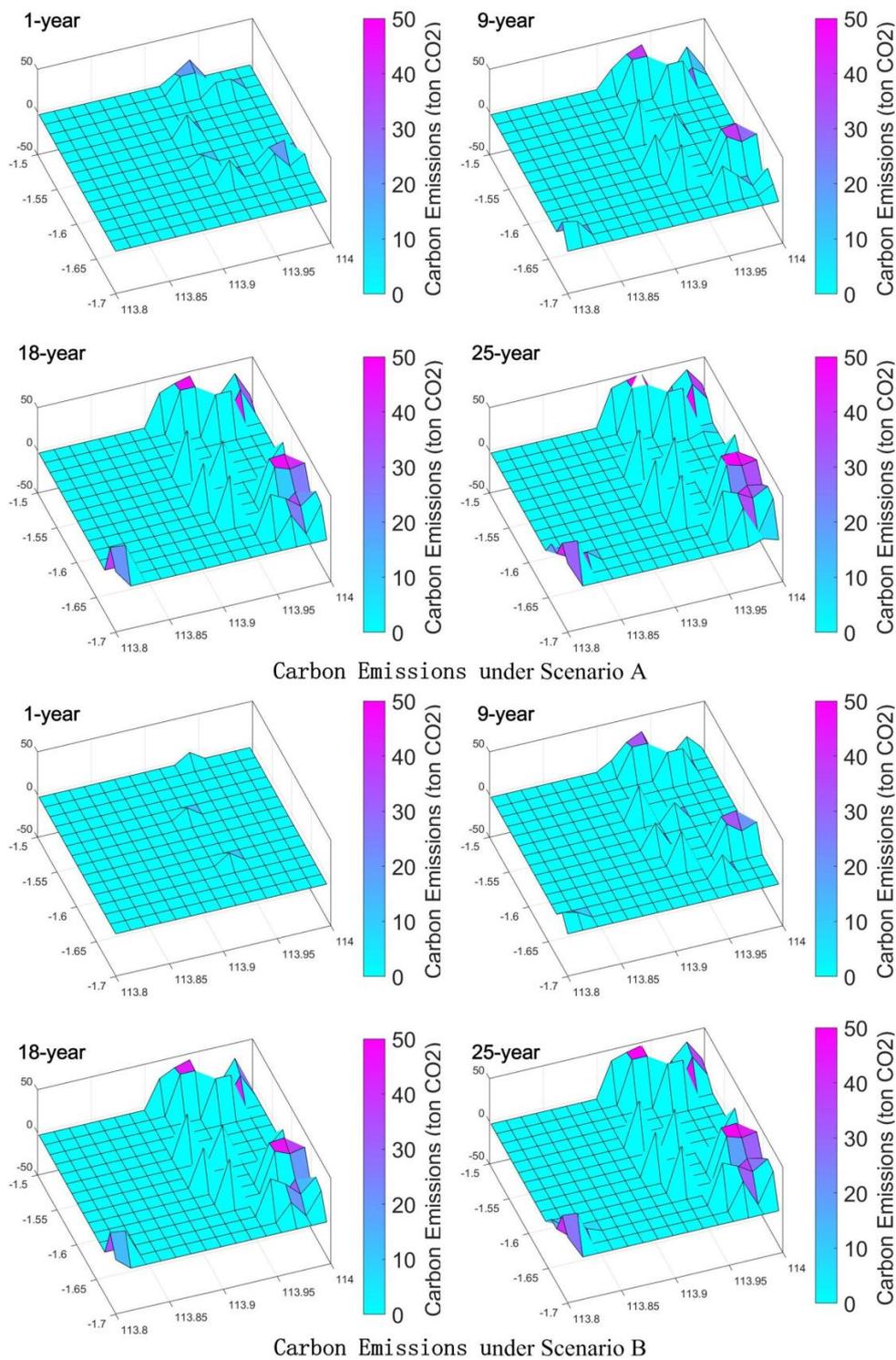
Figure 2. In both color and height, three-dimensional graphs display subtle variations of carbon emissions by predicting future land use changes under two scenarios: (1) Scenario **A**: without consideration of carbon sequestration in plantations, and (2) Scenario **B**: with consideration of carbon sequestration in plantations. X axes represent longitude, Y axes represent latitude, and Z axes represent carbon emissions from deforestation (unit: tonne CO_2) in study area of total 47.9 thousand hectares.

The prediction of the net present value obtained from rice, logging, oil palm plantations, and rubber plantations using Equation (6) is illustrated in Figure 3. Oil palm plantations and rubber plantations will generate USD 15.2 million (with USD 1.57 million in six years) and USD 10.5 million

in revenue in 25 years, respectively. In Indonesia over the last twenty years oil palm and rubber plantations have been the most profitable land use choice for farmers [55,56]. In general, farmers first shifted from rice cultivation to rubber plantation and then to oil palm plantation, due to high yields and relatively low labor wages.
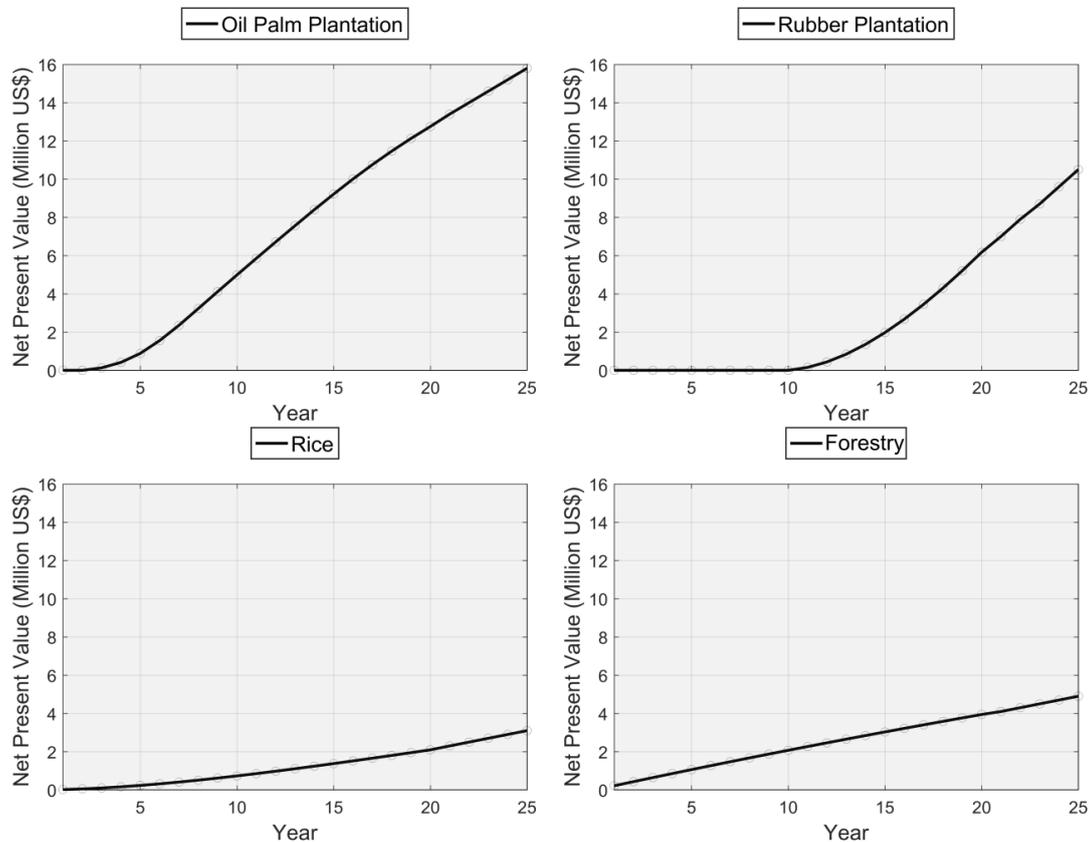

Figure 3. Net revenues for oil palm, rubber, rice, and forestry in the study area in twenty-five years under the business-as-usual (BAU) simulations.

3.3. Opportunity Costs

The IPCC [6] estimated the savings and costs expected from forestry-related activities. For instance, mitigation efforts are predicted to be able to achieve emission reductions of 0.2–13.8 $GtCO_2$/yr at costs of up to USD 100 per ton by 2030, of which about one-third can be achieved at less than USD 20/tCO_2. It is true that the current carbon price has not reached USD 100/tCO_2, indicating that there is still much uncertainty about future climate change and its mitigation costs. As a result, the uncertainties of costs and benefits should be taken into account during the decision making process. Figure 4 illustrates information in this study and from different sources of OC, and shows that OC and its applicability vary significantly by measure, scale, and region. This variability can be attributed to differing local biophysical, socioeconomic, and cultural conditions. According to a new study reviewing 57 REDD+ projects in Southeast Asia, Graham et al. [57] concluded that the cost of reducing emissions ranged from USD 9 to USD 75 per tonne (i.e., from USD 2.45/tCO_2 to USD 20.44/tCO_2 after conversion). This study can be used as a comparison. Our study shows that OC in Kalimantan, Indonesia ranges from 3.5/tCO_2 to 19.6/tCO_2, depending on different social discount rates, with an average value of USD 8.56/tCO_2.
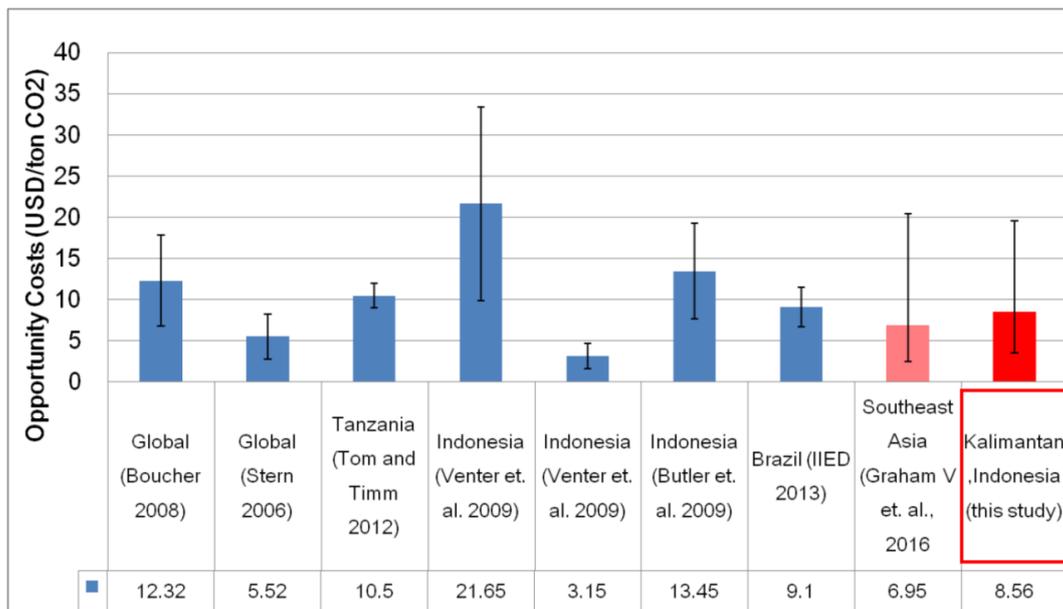
Figure 4. Opportunity costs (OC) from different sources.

3.4. Sensitivity Analysis

Figure 5 shows sensitivity analysis of social discount rate to OC under two scenarios. It shows that OC decreases slowly as social discount rate increases. Under scenario A, the ratio changes by −26% (from USD 19.6 to USD 14.5) as the social discount rate increases by 2.5% (from 2.5% to 5%). In contrast, the change in OC is approximately the same percentage when the social discount rate increases by 5% (from 10% to 15%). Meanwhile, compared with scenario A, which considers the carbon in plantations, OC changes are almost all the same under scenario B, which does not consider the carbon in plantations, when the social discount rate changes from 2.5% to 15%. It is apparent that, relative to the social discount rate, carbon emissions from plantations have a much smaller impact on OC for REDD+ in Kalimantan, Indonesia.
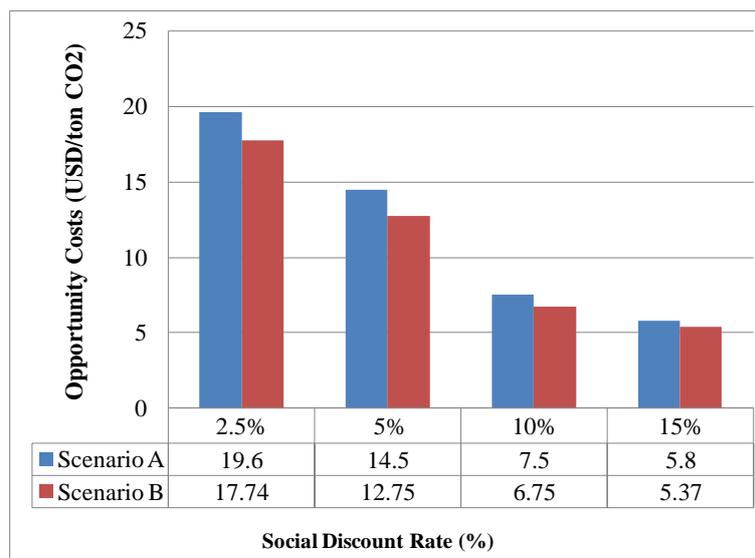

Figure 5. Sensitivity analysis of social discount rate to OC under two scenarios: (1) Scenario A: without consideration of carbon sequestration in plantations, and (2) Scenario B: with consideration of carbon sequestration in plantations.

We conducted a sensitivity analysis by increasing or decreasing plantation area by approximately 10% or 20% of the original value under the two scenarios. For each parameter change, we recorded the percentage impact on OC, which is graphically illustrated using a tornado diagram in Figure 6. Figure 6 shows that, under scenario A (without consideration of carbon in plantations), the change in incremental OC is only approximately 6%, when the oil palm plantation area increases by 10%. When the oil palm plantation area increases by 20%, OC increases from 13.3% to 51.6%. Rubber plantations show the same trend, that is, OC increases from 3% to 13.3% for the 10% case and from 7.5% to 25.5% in the 20% case. Compared with scenario A, OC decreases by 2.3% under scenario B, when the oil palm plantation area increases by 20%.
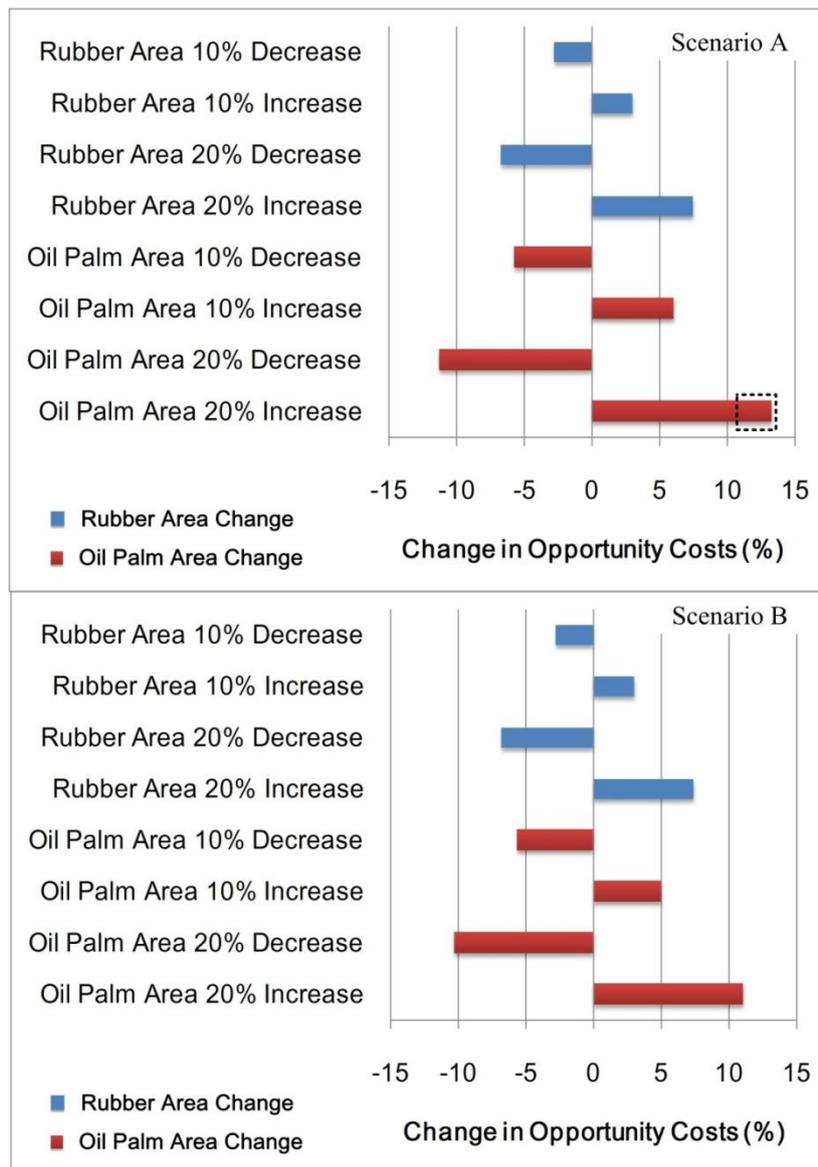

Figure 6. Sensitivity analysis of plantation area to OC under two scenarios: (1) Scenario A: without consideration of carbon sequestration in plantations, and (2) Scenario B: with consideration of carbon sequestration in plantations.

The values for individual oil palm plantations are always larger than those of rubber plantations. For example, under scenario A, when the area increase is 10%, the difference in OC between oil palm and rubber plantations (oil palm plantation minus rubber plantation) is 3%, and for a 20% increment,

it is 5.8%. Under scenario B, the difference is smaller: 1.97% for the 10% case and 3.58% for the 20% case. Thus, we may conclude that OC increases faster in oil palm plantations than in rubber plantations.

4. Policy Implications

This study determined how carbon sequestration from plantations affects opportunity costs of avoided deforestation by defining two scenarios: with and without consideration of carbon sequestration in plantations. In addition, we identified the influences of individual plantations using a sensitivity analysis. Our outputs provided significant insights into the regions' food, plantation agriculture, financial costs, and carbon emissions from the viewpoint of a developing country.

4.1. The Contribution of Carbon Sequestration from Plantations Is Limited on the Opportunity Costs of Avoided Deforestation

It takes about 60 to 80 years for natural forests to reach maximum stock when compared with about 25 years for rubber plantation and about 20 years for oil palm plantation. Although the agricultural plantation sector has a higher carbon sequestration rate (3–5 t C/ha/year) than maturing natural forests (0.5 t C/ha/year), it takes a very long time for the release of forest carbon to the atmosphere to be offset by claimed plantation growth rates [58,59]. Meanwhile the 'production life cycle', which considers the fate of an oil palm or rubber plantation from initial planting until the end of the economic life cycle and replanting, has a short natural lifespan of a couple of decades. In practical terms, this leads to plantations taking a long time to repay the carbon debt on that land. As a result, the effect of carbon sequestration from plantations is limited to the opportunity costs of avoided deforestation.

Furthermore, although carbon sequestration can be expected to offset emissions from land conversion in tropical forests with approximately net neutral effects over a plantation life cycle, these plantations in the species-rich tropics would have catastrophic effects on environmental conservation, and consequently threatening the global biological diversification. As a result, conversion of forests for plantations with high economic viability is putting carbon-rich ecosystems at risk, and thus not the best way to address the challenges of climate changes.

4.2. The Opportunity Cost of Avoided Deforestation in Southeast Asia Will Increase Due to Future Oil Palm Expansion

Our results indicate that OC increases significantly with a rise in oil palm plantations, whereas rubber plantations (as they currently stand) have a smaller effect. This finding is particularly relevant to Kalimantan, which has an accelerated expansion of oil palm plantations [60,61]. Carlson et al. [62] indicate that by 2020, the complete development of allocated leases is predicted to convert a total of 93,844 km^2 of land (~90% forested land, including 41% intact forests) to oil palm plantations. In our study, when the area increased by 20%, the difference in OC between oil palm and rubber plantations increased by 5.8%. Thus, our research provides a strong perspective on OC for local policymakers, who can contribute toward political decision making and the evaluation of the potential of fields. This is especially meaningful, given the need for a locally adaptive regulatory framework to fulfil various climate objectives [63–67].

In Southeast Asia, plantations in Indonesia and Malaysia undoubtedly hold economic importance in the region [68–70]. These financial revenues have become more aggressive with the palm oil price boom. In fact, average crude palm oil prices have increased 2.5 times in real terms, from USD 417/tonne to USD 1041/tonne in recent years, and remain at approximately USD 634.4/tonne as of 2015 [71]. For example, the volume of oil palm brought USD 18.6 billion in foreign exchange revenue into Indonesia when compared with exports decreased by 2.91% to 2.6 million tonnes worth USD 4.74 billion USD for rubber in 2016. With spiraling market prices and relatively low production costs of oil palm, the value of OC is expected to increase significantly [72–75].

The results from local parameters used in this study yield only OC of carbon emissions in north Palangka Raya, Kalimantan, where a REDD+ program is particularly challenging, because of

the accelerated expansion of plantations, and where the impact of plantations on REDD+ program compensation is poorly understood. Although there is no universal solution to the issue of REDD+ OC, our study provides a case that can be applied to other region for evaluating the impacts of plantation carbon sequestration and insights that can help local policymakers design a financially attractive REDD+ program in other tropical forests all over the world.

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