A Spatially Explicit Modeling Framework of Cost-Benefit and Carbon Emissions from Land Use Coverage Changes for Implementing REDD+ in Southeast Asia

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Introduction

Background The United Nations Framework Convention on Climate Change (UNFCCC) agreed that the Reducing Emissions from Deforestation and Forest Degradation plus sustainable management of forests, also known as REDD+, could contribute to the production of carbon sinks, as well as afforestation, reforestation, and revegetation in tropical regions. It is regarded as an essential component of the post-2012 climate regime to stabilize Greenhouse Gas emissions (GHG) and engage developing countries in worldwide mitigation endeavours.

Objective Despite the utility of REDD+, it has raised a number of questions, particularly with respect to its financial costs. This study seeks to contribute to the current debate on REDD+ implementation by focusing on the gap between agricultural revenue from land uses and REDD+ compensation.

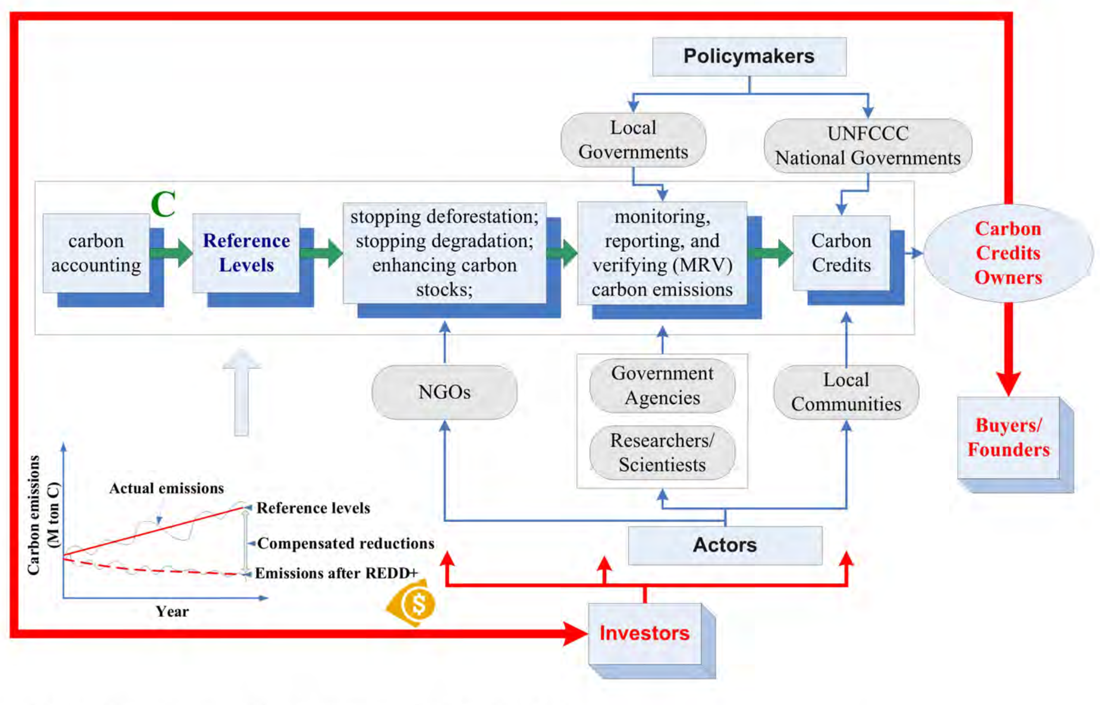
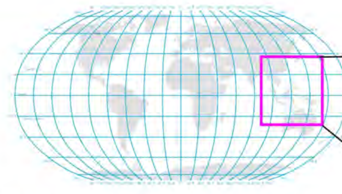


Fig.1 Mechanisms and actors involved in REDD+.
Source: Heli LU, Sustainability (2015); Heli LU, ScienceAsia (2016)

Research Area Central Kalimantan currently is the fastest growing province in Indonesia and features the greatest expansion of oil palm cultivation. Field survey conducted by the international research team have indicated that the clearance of forests is predicted to reach a maximum in the next 30 years while palm plantations expand.



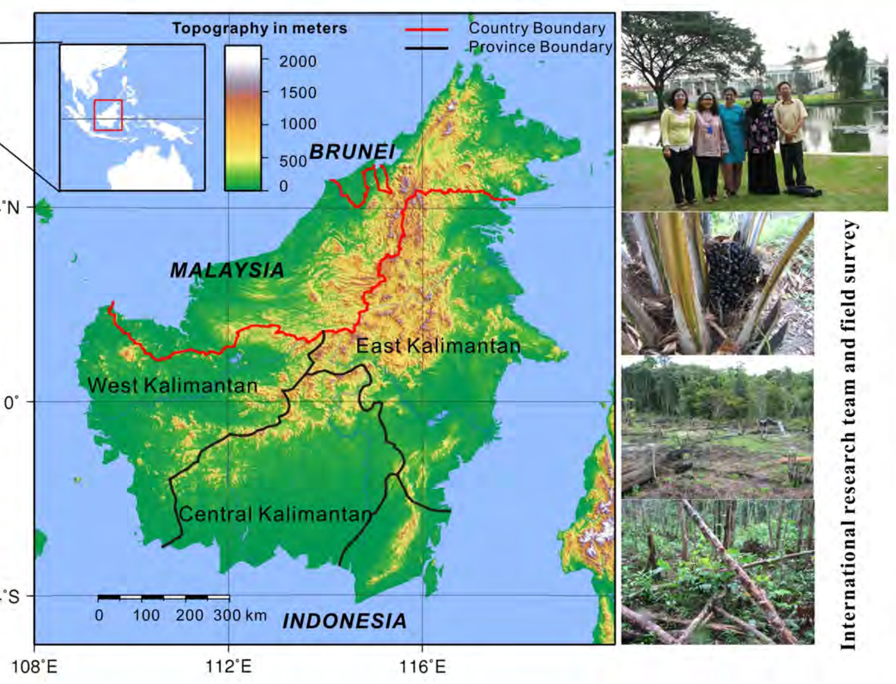
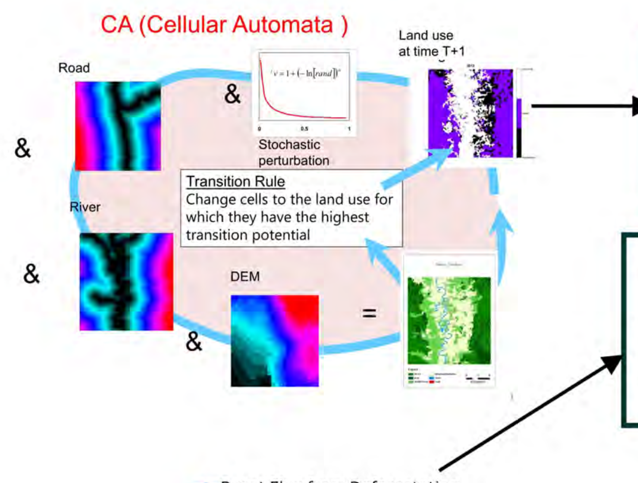


Fig.2 Research area and field survey conducted by the international research team.
Source: Heli LU, Land Use Policy (2013); Heli LU, Chinese Geographical Science (2012)

Materials and Methods



REDD+ MODEL

Land Use Change

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

$$R_i=P\{j\Rightarrow k\mid N_1\cap N_2...\cap N_i\}=e^{\sum W_i^+}/(1+e^{\sum W_i^+})$$

$$N_i=\sum_x\sum_d W_{sxd}I_{xd} \qquad \log\{D\mid N_i\}=\log(D)+W^+$$

Carbon Account

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

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

$$C_{f,regrowth}^{FC}(t)=-\int_0^T A_{SF}(t,\tau)*C_{veg}*0.7/Tdt \qquad C_{f,burn}^{FC}(t)=Bio_{clear}(t)*0.2$$

Planting Profit

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

$$\psi=\ln(1+\gamma)$$

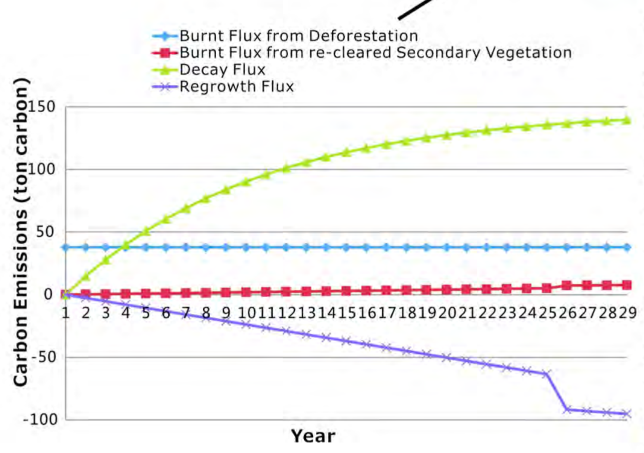
REDD+ Compensation

$$A_t=\int_{\tau=0}^{\tau=t}(M(R_\tau)-\alpha A_\tau)d\tau \qquad W=\int_{t=0}^{t=\infty}U(C_t,E(R_t,A_t))e^{-\rho t}dt \qquad \frac{\dot{\omega}_t}{\omega_t}+Q_{K,t}\omega_t=\rho$$

$$AGWP(CO_2)=\int_0^{TH}a_x[CO_2(t)dt]$$

$$F[CO_2(t)]=0.30036e^{-t/6.6993}+0.34278e^{-t/71.109}+0.35686e^{-t/815.277}$$

Parameter	Description	Value
P_h^{FC}	One-time net revenue from logging per hectare	USD 830
A_1	Price of rice	USD 0.32/kg
A_2	Net revenue per hectare of rubber plantations	USD 75.1
A_3	Net revenue per hectare of oil palm plantations	USD 258.27
γ	Discount rate	10%
θ_1	Total area used for rice cultivation in the expanding agricultural land	16.3%
θ_2	Total area used for rubber plantations in the expanding agricultural land	32.7%
θ_3	Total area used for oil palm plantations in the expanding agricultural land	51%

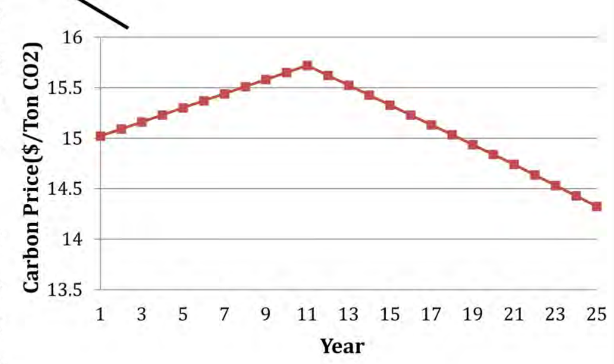


Land use change We linked the business-as-usual (BAU) baseline scenario to historic data. There were two main steps in baseline mapping: determining the deforestation rate and predicting potential locations of future deforestation. Input parameters include elevation, slope, aspect, soil types, distance to road, distance to river, etc.

Carbon account Total carbon emissions due to the plantations were calculated through changes in carbon stocks. The components include the initial conversion of the preceding vegetation into palm oil plantation, the decay of product, slash, and elemental carbon pools and the balance of emissions and absorption during the growth cycle of the oil palms.

Planting profit Potential revenues from palm plantation were calculated by multiplying yields from palm oil products with the corresponding prices. A palm productive model derived using empirical data from the Indonesia Oil Palm Research Institute was utilized in this study. Other revenues include logging, rice cultivation and rubber plantation.

REDD+ compensation Compensation from REDD+ for stopping deforestation involves two factors: carbon credits and carbon price ($/ton CO_2). The so-called "ton-year approach," which had been discussed in the IPCC Special Report on Land Use, Land-Use Change, and Forestry, was adopted for estimating carbon credits. The basic projected carbon price is derived from the dynamic integrated model of climate and the economy (DICE).



Results

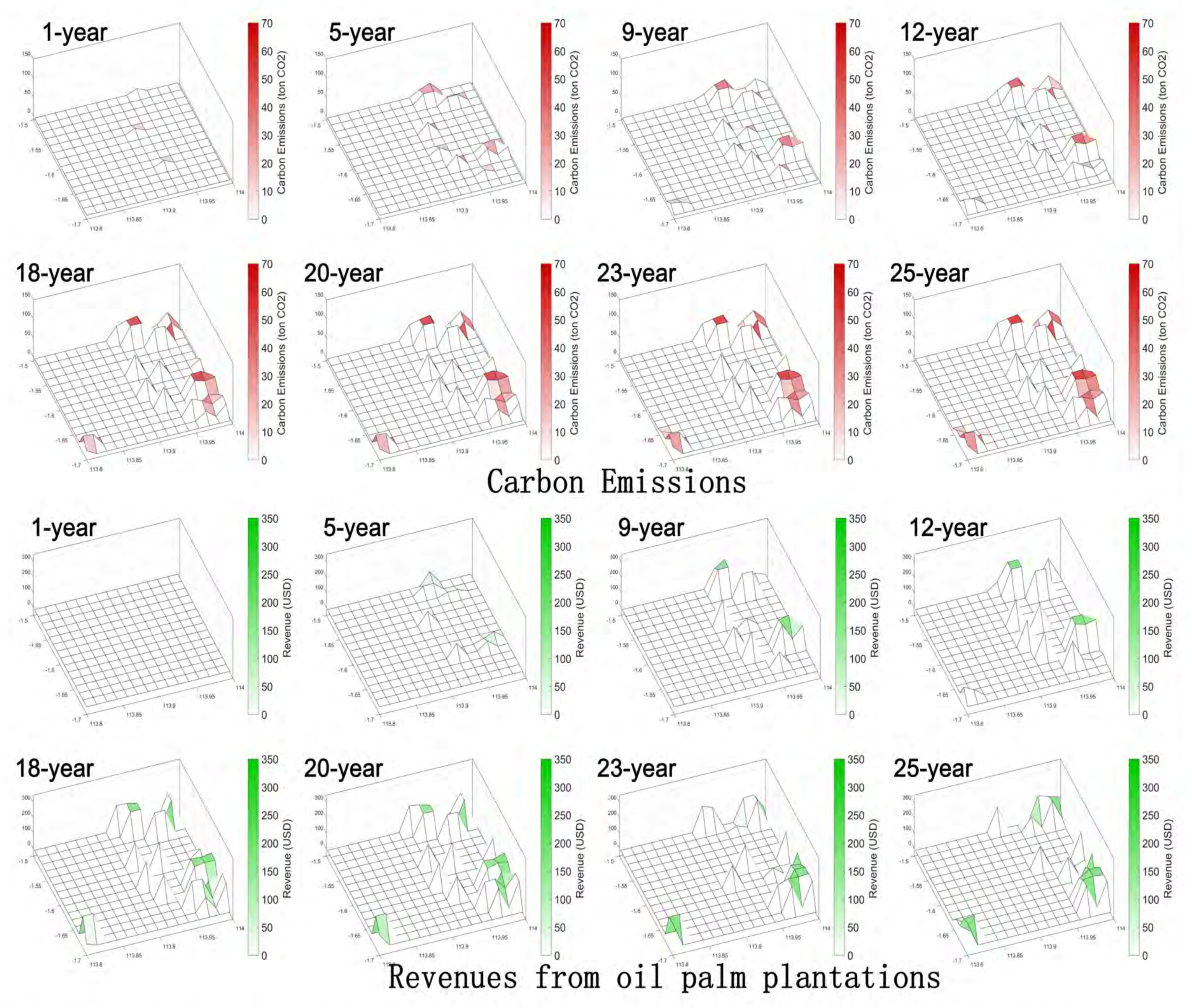


Fig.3 Carbon emission patterns and agricultural revenue evolution in the study area over 25 years. Clear changes are visible in these maps. The background in each map is white. High carbon emissions areas and high agricultural revenue areas are represented in red and green, respectively. This expansion in study area extends from south to north along the river and road.
Source: Heli LU, Natural Resources Forum (2012); Heli LU, Science China: Earth Sciences (2014)

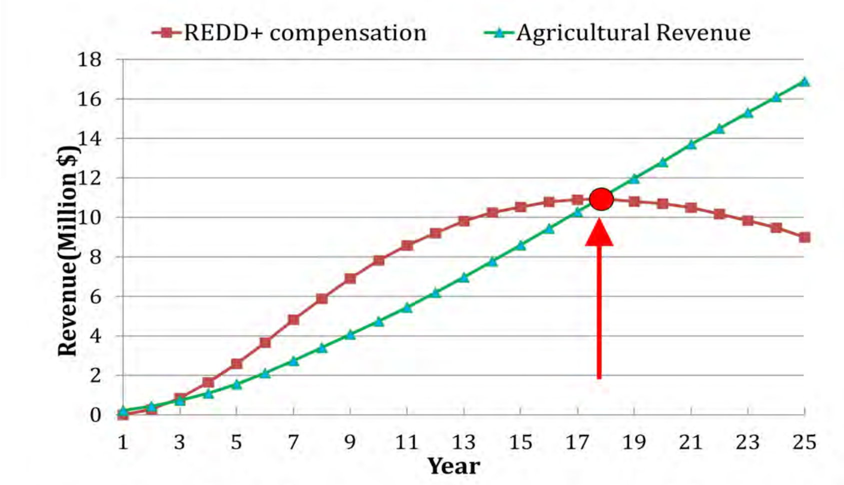


Fig.4 The effect of carbon prices was assessed by plotting REDD+ compensations against time for the agricultural revenue.
Source: Heli LU, Natural Resources Forum (2012)

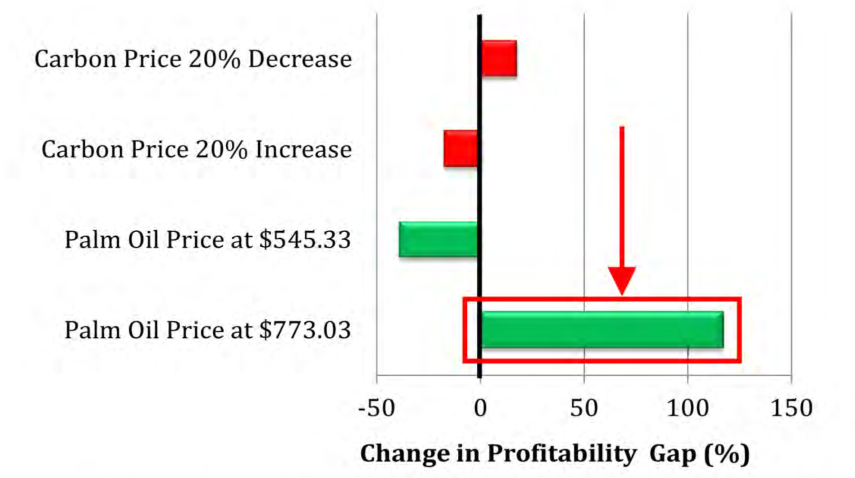


Fig.5 Tornado diagram for sensitivity analysis. The one-way sensitivity analysis was conducted by changing a single key parameter by an increment or decrement of about 20% of its original value.
Source: Heli LU, Land Use Policy (2013)

Profitability Gap (%)		Palm Oil Price										
		545.33	592.16	621.78	653	685.91	709.96	720.59	730.48	746.86	757.15	773.03
Carbon Price (%)	+0	61.1	73.7	86.6	100.0	113.9	174.8	128.3	194.1	199.4	143.2	216.9
	+10	52.4	65.0	77.9	91.3	105.2	166.1	119.6	185.4	190.7	134.5	208.2
	+20	43.7	56.3	69.2	82.6	96.5	157.4	110.9	176.7	182.0	125.8	199.5
	+30	34.9	47.6	60.5	73.9	87.8	148.7	102.2	168.0	173.3	117.1	190.8
	+40	26.2	38.9	51.8	65.2	79.1	140.0	93.4	159.3	164.6	108.4	182.1
	+50	17.5	30.2	43.1	56.5	70.4	131.2	84.7	150.6	155.9	99.7	173.4
	-10	69.8	82.4	95.3	108.7	122.6	183.5	137.0	202.8	208.1	151.9	225.6
	-20	78.5	91.1	104.0	117.4	131.3	192.2	145.7	211.5	216.9	160.6	234.3
	-30	87.2	99.8	112.7	126.1	140.0	200.9	154.4	220.2	225.6	169.3	243.1
	-40	95.9	108.5	121.4	134.8	148.7	209.6	163.1	228.9	234.3	178.0	251.8
	-50	104.6	117.2	130.1	143.5	157.4	218.3	171.8	237.6	243.0	186.7	260.5

Tab.1 Two-way sensitivity analysis. The profitability gap at the palm oil price of $653 and the carbon price of the original DICE model (100% DICE) was set as the baseline. We computed the profitability gaps for 11 levels of carbon price for 11 levels of palm oil prices.
Source: Heli LU, Land Use Policy (2013)

Results analysis

1) The scenarios constructed in this study explore how the carbon price affect the implementation of REDD+. In Figure 4 intersections occur in the graphs because, unlike past projections in which carbon payments had the primary effect on the graph, agricultural revenue has assumed significant importance . It can be seen that REDD+ compensation intersects with agricultural revenue in 18-year and is reduced to 47% of agricultural revenue in 25-year. As a result we project that the gaps between compensation and agricultural revenues increase significantly in this study area over a 25-year period.

2) In a one-way sensitivity analysis, the change in incremental profitability gaps ratio is only about 18% when the carbon price increases by 20%. In contrast, the ratio changes by noteworthy 117% as the price of palm oil increases by almost the same percentage (from $545.33 to $773.03).

3) In a two-way sensitivity analysis , different scenarios of palm oil prices reveal a noticeable effect of plantation demands on land use. At a constant carbon price (100% DICE), moving from $545.33 to $773.03 shows a noticeable 155% increase in the profitability gap. In particular, a decrease of only 44% could be found at the lowest palm oil price ($545.33) and the highest carbon price (+50% DICE).

Conclusions

Policy Remarks A careful assessment of future carbon prices and agricultural revenue in Southeast Asia provides significant insights to projected REDD+ compensation.

1) The most likely forecasts of palm oil prices continue to predict large differences in the profitability gap, favoring palm oil plantation over REDD+ projects. Thus, the effect of carbon pricing policies, as they currently stand, will remain limited. Since country participation is voluntary, it is difficult for the governments to ensure that REDD+ money "reaches the ground" in terms of balancing the agricultural revenue of land users in Southeast Asia. The continuing high demand for biofuels and food puts carbon stocks in tropical forests at risk, and in doing so, potentially undermines efforts to stabilize the atmospheric CO_2 concentration through REDD+.

2) Our study focused on the Southeast Asia region, where forests are directly threatened by future palm oil plantations. However, this research also provides a possible means to evaluate whether the financial benefits from carbon compensation from REDD+ projects could be financially attractive in other forest areas of the world.

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Acknowledgments

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