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A comparative assessment of the financial costs and carbon benefits of REDD+ strategies in Southeast Asia

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Abstract

REDD+ holds potential for mitigating emissions from tropical forest loss by providing financial incentives for carbon stored in forests, but its economic viability is under scrutiny. The primary narrative raised in the literature is that REDD+ will be of limited utility for reducing forest carbon loss in Southeast Asia, while the level of finance committed falls short of profits from alternative land-use activities in the region, including large-scale timber and oil palm operations. Here we assess the financial costs and carbon benefits of various REDD+ strategies deployed in the region. We find the cost of reducing emissions ranges from \$9 to \$75 per tonne of avoided carbon emissions. The strategies focused on reducing forest degradation and promoting forest regrowth are the most cost-effective ways of reducing emissions and used in over 60% of REDD+ projects. By comparing the financial costs and carbon benefits of a broader range of strategies than previously assessed, we highlight the variation between different strategies and draw attention to opportunities where REDD+ can achieve maximum carbon benefits cost-effectively. These findings have broad policy implications for Southeast Asia. Until carbon finance escalates, emissions reductions can be maximized from reforestation, reduced-impact logging and investing in improved management of protected areas. Targeting cost-efficient opportunities for REDD+ is important to improve the efficiency of national REDD+ policy, which in-turn fosters greater financial and political support for the scheme.

1. Introduction

Southeast Asia has the highest rate of forest loss in the tropics, with 11 Mha (10%) of forest cover lost between 2000 and 2010 (Miettinen *et al* 2011). The destruction of tropical forests contributes to ~15% of anthropogenic CO_2 emissions (van der Werf *et al* 2009) and is a major cause of biodiversity declines (Laurance 1999). The most promising international financial mechanism for conserving tropical forests in developing countries is REDD+ (for Reducing Emissions from Deforestation and forest Degradation in developing countries plus conservation of forest carbon stocks, sustainable management of forests, and enhancement of forest carbon stocks; Venter and Koh 2011). REDD+ is often portrayed as providing a win–win scenario in Southeast Asia; as it directs large flows of international finance towards reducing forest carbon emissions, which benefits forest communities, ecosystems and the climate.

REDD+ has received widespread international support since its inception in 2005. Financial support for the scheme totalled US \$7.3 billion by 2015, including pledges of over US \$2 billion to Indonesia alone (for real-time tracking of REDD+ expenditures see: Forest Trends Association 2016). Criticism of

REDD+ covers a multitude of economic, social, ecological and governance issues (McGregor 2010, Agrawal *et al* 2011). For instance, the economic viability of REDD+ depends on whether the finance it generates is sufficient to off-set lost revenues from alternative land-use activities, which in Southeast Asia can include timber extraction, oil palm concessions and smaller-scale agricultural encroachment (Venter and Koh 2011). There are concerns that the program may result in 'fortress conservation' in which the priorities of international investors are privileged over those of local forest users, and that new forms of intimate exclusions will be experienced at the local-scale (Howson and Kindon 2015). Corruption, community opposition (Eilenberg 2015, Lounela 2015), and poor knowledge and communication (Howell 2015) are all governance issues that have stymied project development. Important ecological considerations include the carbon-biodiversity trade-offs of REDD+ activities. For example, afforestation is beneficial for carbon, but can have negative impacts on biodiversity (Bremer and Farley 2010). Although attention has been drawn to the trade-offs between carbon, biodiversity and community livelihoods (Newton *et al* 2016), information is scarce on how these outcomes differ between the type of strategy employed.

In this paper we focus on the economic challenges, particularly in terms of the costs associated with different REDD+ strategies in Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor-Leste and Vietnam, as economic feasibility can influence the success of a project from infancy. Recent research has drawn comparisons of the financial incentives from REDD+ against large-scale oil palm plantations in Southeast Asia (Butler *et al* 2009, Venter *et al* 2009, Fisher *et al* 2011a, Irawan *et al* 2011, Ruslandi *et al* 2011). For example, Fisher *et al* (2011a) estimate that converting a hectare of forest into oil palm in Sabah, Malaysia earns ~\$24 000 over 25 years, which equates to ~\$170 per tonne of emitted carbon—a price which is unlikely to be met through REDD+ financing given the low price of carbon. The consensus from Fisher *et al* (2011a) and Ruslandi *et al* (2011) is that REDD+ will be of limited utility for reducing emissions from oil palm because the revenues from converting forest into oil palm far outweigh the revenues from trading the carbon credits on voluntary markets (Butler *et al* 2009).

However, by focusing solely on reducing emissions from oil palm expansion in forests, such research can overlook potentially more cost-efficient strategies for REDD+. To optimally allocate REDD+ resources, it is important to consider both activities that reduce emissions as well as activities that sequester carbon (van Kooten *et al* 2009). Alternative options for REDD+, other than limiting oil palm expansion, include sustainable forest management practices (Putz *et al* 2008, Griscom 2009), investing in protected areas (PAs) to improve their management and reduce illegal forest loss (Scharlemann *et al* 2010) and forest restoration (Silver *et al* 2000, Alexander *et al* 2011). These strategies provide alternative models for pursuing REDD+ that may be more financially attractive to Southeast Asian nations.

In this paper we provide the first broad comparison of the financial costs and carbon incentives associated with different REDD+ strategies in Southeast Asia. We initially identify what types of strategies are most common in Southeast Asia before estimating the cost-efficiency, measured as the cost of reducing one tonne of carbon, of a subset of REDD+ strategies, for which financial cost and carbon benefit data are publicly available. The research is designed to emphasize and assess the variety of REDD+ strategies being employed in order to inform policy and decision-making regarding the most financially appropriate ways forward.

2. Materials and methods

There were two distinct stages to this review: (1) the assessment of a sample of REDD+ projects being planned or implemented in Southeast Asia; and (2) the collation of cost and benefit estimates of the main strategies adopted by REDD+ projects. The cost and benefit data are hypothetical estimates drawn from the literature and were not sourced from REDD+ projects.

2.1. REDD+ project review

An inventory of forest carbon projects was compiled by searching online REDD databases that were known to the authors or were found by searching the internet for 'REDD databases' (Conservation International 2016, Forest Carbon Asia 2016, Forest Carbon Portal 2016, Forest Climate Centre 2016, Institute for Global Environmental Strategies 2016, The REDD Desk 2016 and Verified Carbon Standard 2016). All projects that were either planned or implemented (regardless of whether they were still operational) as of March 2016 were initially added to the list. We refined the list by applying the selection criteria displayed in figure 1. Reforestation and afforestation projects that were not classified as REDD+ projects were excluded during this stage. The purpose of the project review was to identify the main strategies used by the projects sampled, not to conduct a comprehensive review of REDD+ projects in the region, therefore projects without information on the strategy were excluded. As a result, 57 projects met the selection criteria and no projects were identified in Myanmar, Timor-Leste, Singapore or Thailand. In this paper, a 'project' refers to a site (e.g. Heart of Borneo), while a 'strategy' refers to the approach adopted at a site to reduce emissions or promote sequestration by forests. The proponents were divided into the following four categories:

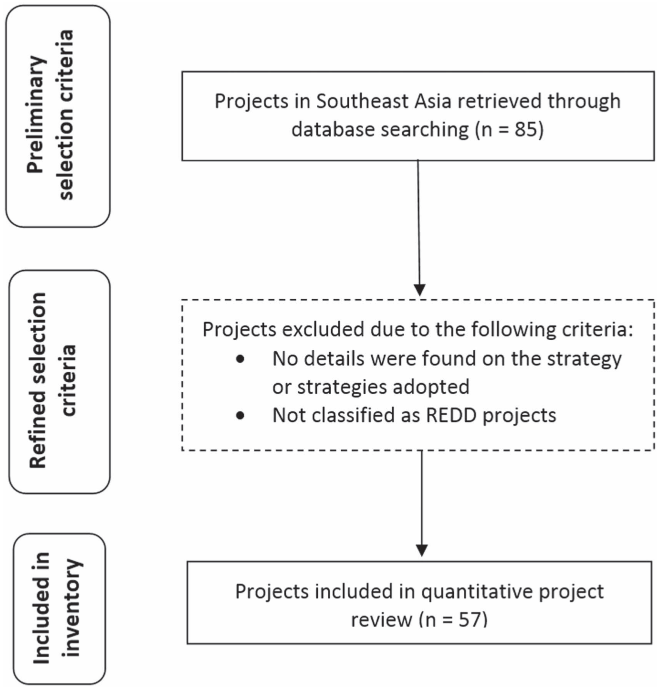

Figure 1. Flow chart showing the selection criteria used to generate the list of REDD+ projects in Southeast Asia as of March 2016. Dashed lines represent where the selection criteria were applied to exclude projects. A total of 57 projects were included in the final inventory.

government, non-governmental organization (NGO), private company, and research institution.

Once an inventory of projects was compiled, we used proponent websites and project proposal documents to extract data on specific projects, including: name, geographic location, strategies adopted, area under management (hectares), proponents, planned duration, driver of deforestation and targeted or realized emissions reductions. Each planned or existing project was categorized into at least one of the strategies shown in table 1 based on key terms identified in the project description. The strategy list was based on an initial literature search and modified as the review progressed, such as adding or deleting categories based on their prevalence. We assigned projects to more than one category if they adopted multiple strategies. For example, the Heart of Borneo project covers 16 800 000 ha, spans three countries, and adopts seven different strategies. We classified this project as three projects (to represent each country), each with seven strategies.

2.2. Cost-benefit analysis

Our cost-benefit analysis focuses on the financial viability of different strategies for reducing emissions as one component influencing broader REDD+ discussions, while drawing attention to the social and ecological dimensions of these strategies, which are also important project outcomes. At this early stage in its development, all but the most advanced REDD+ nations are yet to develop national capacities for measuring and reporting on non-carbon benefits and safeguards (Vijge *et al* 2016).

We used systematic search protocols (Moher *et al* 2009) to collect financial cost and carbon benefit data for the strategies (table 1) to directly compare their cost-efficiency, as measured by the estimated financial cost of reducing one tonne of carbon emissions. The financial costs and carbon benefit data were collected from the respective bodies of literature, to provide representative estimates of the cost-efficiency of REDD+ strategies. We searched for data in peer-reviewed books, journals, reports published by government and non-government agencies, using terms specific to each strategy (such as: 'costs' or 'carbon benefits' and 'reduced-impact logging' (RIL)) and examined the reference lists of suitable literature to locate further data. We included estimates from the 'grey literature' to ensure we collated multiple estimates for each strategy, as some strategies did not feature in the peer-reviewed literature. Once we identified all possible information sources, we removed studies that were duplicates (i.e. the published manuscript from an unpublished university thesis) or that were not in English. We further refined the list based on eligibility in meeting the following criteria: (1) the research was conducted in Southeast Asia—with the exception of the reforestation strategy as there was insufficient regional data so we expanded our search to tropical regions outside Southeast Asia; (2) the carbon emissions for RIL presented a 'before-after' scenario of RIL versus conventional logging (CL); and (3) the data was not for activities on peat

Table 1. List of strategies included in the REDD+ project inventory with a description of the strategy and the business as usual scenario against which it was assessed, whether the costs were estimated in our study and which costs were included. In the literature, different cost components (opportunity costs, management costs and/or transaction costs) were estimated for different strategies. For example, the protected area strategy was based on the costs of managing a park to effectively reduce forest loss (including the purchase of infrastructure items as well as staffing requirements), less the current budget allocated (i.e. the budget shortfall) and did not include opportunity costs. For the oil palm and timber strategies, financial costs were based on opportunity costs (including lost profits from the sale of timber from pre-clearing prior to planting) and transaction costs. For reforestation, opportunity costs were not included because the reforestation strategy targets abandoned land that is not being used for plantation agriculture or logging (see supporting information for more details).

REDD+ strategy	Description of strategy	Business as usual scenario	Costs estimated	Cost component
Oil palm	Buying land that was planned for oil palm development before it is cleared and protecting it from forest carbon loss.	Establish oil palm plantation	Yes	OC, TC
Timber	Buying land that was planned for timber plantations before it is cleared and protecting it from forest carbon loss.	Establish timber plantation	Yes	OC, TC
Community encroachment	Buying land that was planned for small-scale agriculture, rice and coffee plantations, risks development encroachment or other local threats before it is cleared and protecting it from forest carbon loss.	Establish small-scale agriculture	No[6]	
Reduced-impact logging	Promoting sustainable forest management practices, such as Reduced Impact Logging, in areas designated for logging, to reduce carbon lost during the logging process. Practices include reducing road and landing pad construction impacts, and reducing collateral damage to remaining trees during felling and extraction.	Conventional logging	Yes	OC, MC, TC
Protected areas	Investing in improved protected area management to prevent forest carbon loss through illegal clearing, logging and fire.	Continue current management plan	Yes	MC, TC
Permit swaps	Working with oil palm developers to retire oil palm permits in high carbon areas and identify alternative sites to establish plantations in low carbon degraded areas via oil palm 'permit swaps'.	Establish oil palm plantation	No[6]	
Reforestation	Identifying cleared or degraded land that is not being actively used for plantations or logging and restoring forests (and peat swamp forests) for carbon storage.	Land remains abandoned[7]	Yes	MC, TC

[6] The costs and benefits of the 'community encroachment' strategy were not estimated because they were considered to be too variable to capture with a single estimate. The 'permit swaps' strategy had insufficient data available to estimate the costs and benefits.

[7] We classify abandoned land in this paper as degraded forest that is not being actively managed for plantations or logging by a person or corporation. However, land that appears abandoned is not always abandoned. In many areas insecure land tenure makes the task of identifying potential land for reforestation a considerable challenge. There are millions of hectares of degraded forest in Indonesia that are considered idle, which present a vast opportunity for improving carbon storage by promoting forest regrowth (Boer 2012, Budiharta *et al* 2014), but some of these areas that are close to villages are being actively worked by neighboring communities. Methods for identifying degraded areas for plantations have been prescribed that utilize spatial information and community surveys (Gingold *et al* 2012).

soils (see section 2.2.2 for rationale). All remaining data sources were included in the review. Here we present a summarized version of the steps involved in calculating the costs and benefits; see supporting information for more details.

2.2.1. Financial costs

In our study, the financial costs of REDD+ projects included opportunity costs, management costs and transaction costs. Opportunity costs are defined as costs of foregone opportunities from the next best use of a resource if not for the current use (Naidoo *et al* 2006). Management costs are ongoing and include operating and maintenance expenses (Naidoo *et al* 2006). Transaction costs include one-off costs of identifying and negotiating REDD+ projects and the ongoing costs of monitoring, reporting and verifying on carbon emissions (Pearson *et al* 2014). The total economic costs of REDD+ also include downstream costs, such as taxes paid to the government, however the majority of the cost literature we examined was focused on financial costs (such as lost revenue from timber extraction). Opportunity costs account for the largest share of total REDD+ costs (Pagiola and Bosquet 2009), however transaction costs can be significant additional costs depending on the project scale (Fisher *et al* 2011b). Strategy-specific estimates of transaction costs are not available in the literature, therefore we applied a generic estimate of transaction costs for a REDD+ project (US $2.21 per tCO_2 or $89 per ha; Pearson *et al* 2014). Insurance (buffering the risk associated with non-permanence) accounts for the largest share of transaction costs, followed by monitoring and regulatory approval costs, whereas search, feasibility and negotiation costs account for a low portion of transaction costs (Pearson *et al* 2014). We relied on the available data to estimate and compare the costs of different strategies, recognizing there are differences in the costs accounted for between strategies. Table 1 explains which cost components were estimated for each strategy.

Net present value (NPV) is the most commonly used measure of REDD+ project costs, which is the discounted value of the sum of projected future cash flows expected under the business as usual scenario (Stone 1988). To maintain consistency between estimates we prioritized NPVs extrapolated over 30 years, which is consistent with the average timeframe for timber and oil palm concessions (Irawan *et al* 2011). Most studies applied a discount rate of 10% per annum, which is not unusually high in the developing country context (Dang Phan *et al* 2014). We standardized all financial estimates into a single currency and year (US 2010) using the national inflation rate for the respective country (The World Bank 2016) and the 2010 exchange rate (XE 2016). If the financial analysis paper used estimates of carbon benefits to calculate the cost of reducing emissions, we used the individual $\$\ tC^{-1}$ figures from the paper, otherwise we calculated the price of reducing emissions using an average carbon benefit from the literature.

2.2.2. Carbon benefits

In our paper, the carbon benefit is the net emissions reduced by each strategy or the carbon sequestered by regenerating forests (see supporting information for details). The carbon estimates used here are from the loss of above- and below-ground carbon (AGC; BGC). We used a root:shoot ratio of 21:100 to convert AGC to total carbon in natural forests and timber plantations (Saatchi *et al* 2011, Kotowska *et al* 2015) and 32:100 in oil palm concessions and swidden agriculture (Kotowska *et al* 2015; see below). We opted to omit carbon-rich peat soils because the impacts of different strategies on peat soils was not consistently available. For the oil palm strategy, the carbon benefit was measured as the difference in carbon stored between oil palm plantations and natural forest in Southeast Asia. A similar comparison was made between natural forest and timber plantations. We ascertained from the literature the carbon emissions reduced by engaging RIL compared to CL techniques. Cacao, oil palm, rubber and coffee (hereafter 'swidden') are commonly planted crops in Indonesian PAs following deforestation (Swallow *et al* 2007). We estimated the carbon lost from the conversion of forests to swidden agriculture and multiplied it by the deforestation rate to project the carbon emissions from illegal deforestation. Finally, for the reforestation strategy, we estimated the 30 year sequestration rate of regenerating forests. The carbon sequestration estimates for reforestation included tropical regions other than Southeast Asia, as there was insufficient regional data available. All carbon values are in tonnes (1 tonne = 1 Mg) of carbon (C). Carbon dioxide (CO_2) was converted to carbon by dividing by 3.67 (van Kooten *et al* 2004). Biomass was converted to carbon by multiplying by 0.492 (Pinard and Putz 1996).

2.2.3. Cost of reducing emissions

We calculated the cost of reducing emissions ($\$\ tC^{-1}$) by dividing the cost per hectare ($\$\ ha^{-1}$) by the carbon benefit per hectare ($tC\ ha^{-1}$), using the formula below, to directly compare the cost-efficiency of each strategy and for ease of comparison against carbon prices.

$$\$\ tC^{-1} = \frac{\$\ ha^{-1}}{tC\ ha^{-1}}$$

where $\$\ tC^{-1}$ = the cost of reducing one tonne of carbon, $\$\ ha^{-1}$ = the cost per hectare, and $tC\ ha^{-1}$ = tonnes of carbon reduced per hectare

3. Results

We found that Indonesia is the regional leader in REDD+ projects, hosting 39 out of the 57 projects surveyed in Southeast Asia (figure 2; see supporting

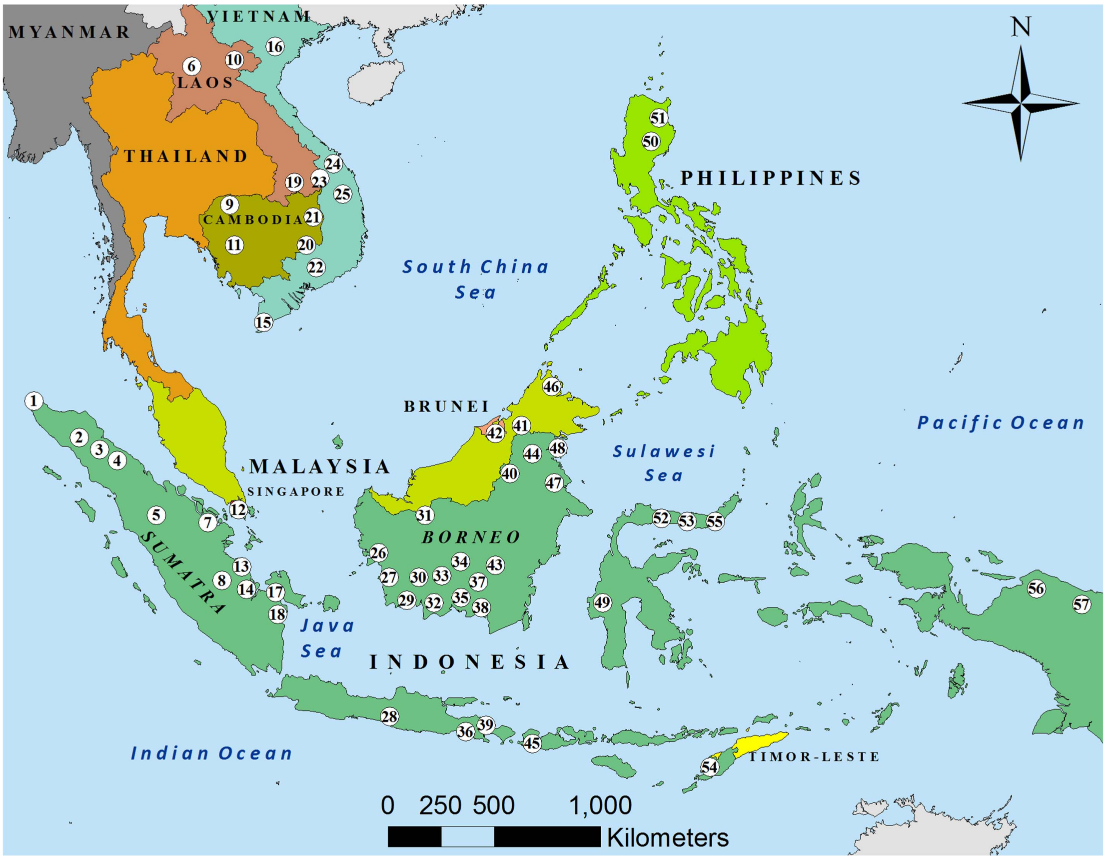

Figure 2. Southeast Asia showing the location of 57 REDD+ projects as of March 2016 that were included in the project review. Refer to supporting information 2 for details of the 57 projects including the name, country and strategy (or strategies) employed at each site.

information 2 for details). Vietnam hosted five projects, Cambodia and Laos hosted four projects each, Malaysia and the Philippines hosted two projects each and Brunei hosted one project. In Indonesia, projects are concentrated on the islands of Borneo and Sumatra; which are the two islands that experienced the highest forest loss for 2000–2010 (Miettinen *et al* 2011).

REDD+ projects primarily deployed seven main strategies: (1) reducing deforestation from oil palm, (2) reducing deforestation from timber plantations, (3) reducing deforestation from community threats (such as subsistence agriculture), (4) employing RIL techniques to reduce wastage and collateral damage during log harvesting operations, (5) improving the management of PAs to reduce fires and illegal logging, (6) moving oil palm permits to degraded land with suitable growing conditions ('permit swaps'), and (7) reforestation (including afforestation and peat restoration). Of these, reforestation was the most common strategy, used at 42 of the 57 project sites (figure 3). Improving the management of PAs was the second-most commonly used strategy (adopted at 35 sites). Agroforestry was grouped into the 'other' category and was commonly implemented adjacent to PAs to buffer the conservation zone from broader landscape threats. RIL was adopted at 17 sites and more commonly adopted by research institutions and private companies than NGOs or governments. Avoiding deforestation from oil palm was less commonly adopted (at 12 sites), followed by oil palm permit swaps (adopted at 9 sites). Projects targeting oil palm were implemented more by NGOs than other proponents. On average, 3 strategies were adopted at each of the 57 project sites. Projects developed by private companies made up the largest share of total projects (39%), followed by NGOs (32%), governments (24%) and research institutions (5%).

The average cost of reducing one tonne of carbon by employing the REDD+ strategies that we reviewed ranged from \$9 to \$75 tC^{-1} (table 2). There is a high level of variation in estimates of both costs and carbon benefits between strategies. We found that reforestation was the most cost-efficient strategy (\$9 tC^{-1}), followed by investing in PAs to reduce illegal forest loss (\$13 tC^{-1}), employing RIL techniques instead of CL (\$25 tC^{-1}), reducing the expansion of timber plantations into forested areas (\$35 tC^{-1}), and limiting the expansion of oil palm concessions into forests (\$75 tC^{-1}). Employing RIL techniques had the lowest per hectare carbon benefit (42tC ha^{-1}), but was the third-most cost-efficient strategy for reducing emissions due to low per hectare opportunity costs. Although stopping the expansion of oil palm into

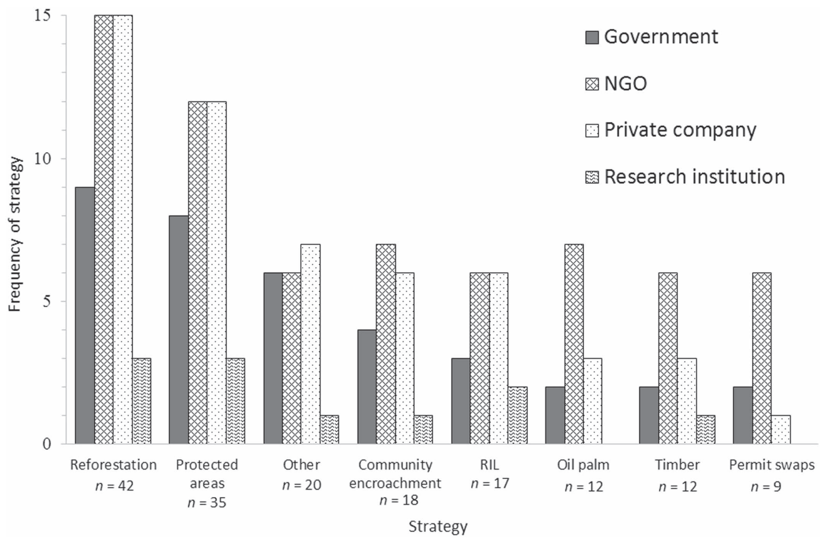

Figure 3. The frequency of REDD+ projects in Southeast Asia that adopt each of the strategies we assessed. On average, three strategies were adopted at each of the 57 project sites. RIL: reduced-impact logging; Other strategies include: agroforestry, agricultural intensification and improving land tenure.

Table 2. Mean cost (US$ 2010) and carbon benefit estimates per hectare and the cost per tonne of carbon reduced for REDD+ strategies in Southeast Asia. Values in parentheses represent the range of estimates. The cost and benefit (measured by C) per hectare were estimated over 30 years. The mean cost per hectare of oil palm and timber plantations includes the profits from timber extraction prior to planting.

REDD+ Strategy	Cost per ha ($ ha^{-1})	Carbon benefit per ha (tC ha^{-1})	Cost per tC ($ tC^{-1})
(a) Timber	4383	133.02	35.34
	(1506–11 735)	(46.82–199.85)	(17.95–64.96)
(b) Oil palm	9942	144.20	74.90
	(2112–28 352)	(80.72–235.39)	(20.74–202.71)
(c) RIL[8]	833	41.77	25.49
	(159–2150)	(33.00–51.38)	(8.66–58.40)
(d) Protected areas	689	90.96	13.38
	(319–1411)	(22.39–159.33)	(9.31–21.31)
(e) Reforestation	1743	192.96	9.03
	(606–4193)	(136.90–251.40)	(3.14–21.73)

[8] Reduced-impact logging.

forests had the second-largest carbon benefit (144tC ha^{-1}), the high yields and value of oil palm as a commodity result in high opportunity costs of employing this strategy. As a result, limiting oil palm was the most expensive REDD+ strategy both per hectare and for reducing one tonne of carbon emissions.

In the financial cost literature, there was more research focused on estimating the opportunity cost of oil palm than on any other strategy. In contrast, there was no single paper that estimated the projected carbon benefits of investing in improved PA management in Southeast Asia, despite the well-documented poor performance of Indonesian PAs (James *et al* 1999, Bruner *et al* 2004, Gaveau *et al* 2007, 2009). Reducing the expansion of timber plantations was the second most expensive strategy due to the high prices attracted by timber from parts of the region (Ruslandi *et al* 2011). While reforestation was costly to implement ($1743 ha^{-1}), it had the largest carbon benefit of all strategies (193tC ha^{-1}), making it the cheapest strategy per tonne of carbon reduced. Additional costs for reforestation on degraded peatlands amount to $240 ha^{-1} for building mounds to improve seedling survival rates in flood-prone areas and maintaining dams where peat canals have been drained (Silber 2011, Budiharta *et al* 2014), which when combined with the cost of reforestation inflates the cost to $1983 ha^{-1} or $10 tC^{-1}. The data sources interrogated for the financial and carbon estimates are detailed in the supporting information.

4. Discussion

Our review of REDD+ projects assesses the economic cost and carbon benefit of a range of strategies oriented at mitigating climate change by improving the amount of carbon stored in Southeast Asian forests. We estimate that reducing emissions through REDD+ would cost between $9 and $75 tC^{-1}, depending on the strategy employed. For comparison against market prices, the 2010 end-of-year carbon price was US \$89 tC^{-1} (www.investing.com). Reforestation and investing more funds into PA management were the most cost-efficient and widely adopted strategies used in over 60% of projects. In contrast to its high profile in the literature, reducing deforestation from oil palm was the most expensive and one of the least commonly used strategies in Southeast Asia. It is our contention that the prevalence of a particular strategy is at least partly a reflection of its cost-effectiveness alongside other considerations deriving from local political economies.

Although high costs have been a documented limitation to the widespread practice of reforestation in some regions (Erskine 2002), reforestation was the least costly strategy for reducing one tonne of carbon that was assessed in our review and the most prolific strategy adopted by REDD+ projects. We expect this result is influenced by low labor costs in Southeast Asia and the high rate of carbon sequestration in regenerating tropical forests (Silver *et al* 2000). Alongside carbon and financial considerations, the social and ecological outcomes of REDD+ strategies are also important to consider when comparing strategies. In the case of reforestation, grasslands that are misconceived as degraded lands and deemed suitable for reforestation pose severe risks to biodiversity (Veldman *et al* 2015). Also, targeting threatened species conservation in addition to carbon storage can reduce the carbon incentive of reforestation by up to 24% compared to efforts that purely target low-cost carbon storage due to trade-offs between carbon and biodiversity (Budiharta *et al* 2014). There are 6.1 Mha of low carbon, degraded land in East Kalimantan (Indonesian Borneo) that are considered suitable for forest regrowth (Budiharta *et al* 2014), therefore the scope for this strategy is vast.

The second most popular strategy was to invest funds into improved PA management. This involves better policing and surveillance as well as infrastructure, education and training programs to prevent illegal logging and agricultural encroachment—both of which are common in many parts of Southeast Asia (Curran *et al* 2004, Gaveau *et al* 2007). The incentives of improved PA management include the carbon gains alongside benefits to biodiversity, tourism and, if well managed, local livelihoods through non-timber forest economies. The biodiversity and community benefits have proved useful for appealing to investors coming from a corporate social responsibility angle, who are seeking 'good news' stories that go beyond profit motives (Dixon and Challies 2015). As for all projects, the risk of failure is high if the local drivers of forest loss are not addressed, however inadequate funding of PAs plays a large role in illegal forest exploitation due to weak law enforcement (James *et al* 1999, Bruner *et al* 2004), which can potentially be addressed with REDD+ finance.

The third most cost-effective strategy was RIL, which was employed at approximately one third of the project sites. This shows that carbon interests are becoming better understood and influential in the forestry sector, with REDD+ proponents seeking to influence how timber is harvested. The benefits to the forestry industry of employing sustainable forestry practises are two-fold; it is a certified-REDD+ strategy which can generate income for the sector, and it can also increase future timber harvests by adopting more sustainable and less damaging logging techniques (Pinard and Putz 1997). Selectively logged forests also have important biodiversity value. For example, once-logged forests retain 76% of carbon and 85%–100% of species of mammals, birds, invertebrates and plants as pre-logged forests (Edwards *et al* 2010, Putz *et al* 2012). However, less than one percent of total tropical forest area in Asia is under certified forest management (Siry *et al* 2005). Given these environmental benefits, there is potential to considerably expand RIL projects at the expense of conventional logging operations, and off-set the financial costs with REDD+ revenue. A perverse risk could be if REDD+ is used to generate the required capital to commence logging operations that were previously underfinanced.

Our results show that buying oil palm and timber permits, where operations cause severe degradation or deforestation and conserving these forests, are expensive options for REDD+. The destruction of forests for oil palm has been a rapidly increasing trend over the past 40 years in Indonesia and Malaysia (Koh and Wilcove 2008) and is a key source of deforestation in Southeast Asia, alongside the production of other agricultural commodities such as rubber and coffee (Stibig *et al* 2014). Limiting the expansion of new oil palm and timber plantations in forests is vitally important for biodiversity conservation, however it is an expensive practice to pursue for the purpose of mitigating emissions. There is also limited scope for REDD+ to target oil palm and timber concessions when compared to other industries. In Indonesia, ~2.7 Mha of remnant forest is contained in timber concessions and ~1.7 Mha in oil palm concessions, compared to ~17.1 Mha in logging concessions (Abood *et al* 2015) and a PA network covering ~22.6 Mha (IUCN and UNEP-WCMC 2016). The relatively low uptake of oil palm and timber projects indicates a reluctance from REDD+ proponents to engage in these activities, for financial and/or political reasons, and a challenge in convincing concession holders to cooperate. In terms of oil palm, we found some interesting initiatives oriented at redirecting plantations to low carbon degraded land. Oil palm permit swapping provides a pathway for furthering agricultural expansion without the loss of additional tropical forests (Venter *et al* 2012). It involves retiring existing permits on carbon dense land and taking-out new permits on highly degraded land that has suitable climatic and edaphic conditions for cultivating oil palm, by undertaking spatial-targeting and community surveys of candidate sites (Gingold *et al* 2012). The benefits of permit swapping are manifold; reducing emissions from the oil palm sector whilst also finding productive uses for abandoned land. The costs incurred from this process include purchasing new permits, negotiating with affected permit holders, communities and governments (Venter *et al* 2012), and can include substantial legal costs. Of critical importance is ensuring that the interests of those using abandoned or degraded land are actively involved in any decision-making about future plans (McGregor 2015).

The following caveats should be considered when interpreting our results. The cost and benefit estimates we present here are averages, however spatial variation has a large influence on the costs and benefits of REDD+ projects (Pagiola and Bosquet 2009). This can be interpreted from the high level of variation in both the cost and carbon benefit estimates within strategies. For example, opportunity costs will vary based on terrain and distance to markets, and carbon benefits will vary based on soil type. Reducing emissions undertaken on peat soils would result in larger carbon benefits (Page *et al* 2002) and hence lower costs than mineral soils. Despite the portrayal in our paper, land use trajectories are not mutually exclusive and most projects employ numerous strategies at a site to combat the range of land-use pressures affecting any given location. In addition, strategy-specific transaction costs of REDD+ were not available in the literature, therefore we applied a generic cost across all strategies, however these could vary significantly between strategies. It should be noted that the literature we reviewed used different methods to calculate the costs and benefits of REDD+ strategies, with not all papers including the same cost components or carbon pools. The purpose of this paper was not to address the finer-scale variation, an important area for future research, but to explore the broad cost-efficiencies of a range of REDD+ strategies.

In terms of strategies, we did not collect quantitative estimates of the categories we termed 'community encroachment' or 'other' because we felt the costs and benefits would be too variable to capture with a single estimate. We also found that the reforestation literature was incomplete and contained no estimates of the costs of natural forest regeneration in Southeast Asia. Rather than omit this strategy from the analysis, we used cost estimates of monocultures as a proxy and included carbon sequestration estimates from other tropical regions. Understanding the costs of assisted natural reforestation is an important area for future research, given the high number of projects undertaking this strategy, and its likely focus within Indonesia's recently announced Peatland Restoration Agency.

5. Conclusions

When REDD+ was first conceived it sought to Reduce Emissions from Deforestation (RED; see den Besten *et al* 2014). As it expanded to reducing degradation (REDD) as well as conserving and sustainably managing forests, and enhancing forest carbon stocks (REDD+), a range of new opportunities opened up for targeting forest carbon loss, including RIL, reforestation and investing in improved PA management. Our analysis shows that these recently included strategies are more common and cheaper in the Southeast Asian region than the former that target high profit and politically-sensitive industries, such as oil palm and timber. The debate about REDD+, however, often remains focused on whether or not it can compete economically with these lucrative industries. Based on the relatively modest profits from forest carbon financing compared to the profits from oil palm and timber plantations, REDD+ will remain ill-suited to slowing these intensive industries across the region. However, this does not mean that REDD+ is failing but that it is shifting from its original focus towards more economical and less politically contentious activities. The discussion about REDD+ needs to be reoriented towards what REDD+ can and cannot do within its current budget. These findings have broad policy implications for Southeast Asia. Until carbon finance escalates, emissions reductions could be maximized from reforestation, RIL and increased investment in PA management. This does not mean that all projects focused on slowing the expansion of oil palm are unviable, but that regional plans for mitigating climate change will achieve maximum carbon outcomes within the current budget by pursuing alternative strategies. Targeting cost-efficient opportunities for REDD+ is important to improve the efficiency of national REDD+ policy, which in-turn fosters greater financial and political support for the scheme. As REDD+ projects are designed to address site-specific environmental threats and consider the unique socio-political context in which they exist, these broad patterns of cost-effectiveness need to be supported by finer-scale research into the spatial variation in costs, carbon benefits, biodiversity and social implications. These issues should continue being explored and the research outcomes used to guide spatially targeted REDD+ projects that support national forest management plans.

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