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National REDD+ outcompetes gold and logging: The potential of cleaning profit chains

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ABSTRACT

Prominent recent evaluations of global research on REDD+ progress (Reducing Emissions from Deforestation and forest Degradation) conclude that 'progress has been slower than expected', 'deforestation and degradation are deeply-rooted in powerful business-as-usual interests' and that '[f]or the most part, new coalitions calling for change in forest governance have failed to overcome business-as-usual deforestation.' Others have earlier pointed out that REDD+ will incentivize land grabbing (potentially endangering customary use rights of forest-dependent citizens), and will remain financially uncompetitive against current commercial forest uses. Combining nationwide data over a decade from Guyana's United Nations-approved Forest Reference Emission Level (FREL) submission and national documents, we found that REDD+ implemented at national level would annually add almost a quarter to the country's budget, and should not incentivize land grabbing as it places little direct value on forest, but financial penalties (lost income) on forest damage. We show quantitatively that national REDD+ in Guyana is competitive on a hectare basis when viewed from the resource owner's perspective, even against high value commodities such as gold and timber (the country's main emission drivers), and at a preliminary US$5 carbon price. Hidden by the latter appears a very lopsided distribution of overall net revenue between the state and private sector commodity chains (~1:99 and ~1:1200). We show government or electorate pressure towards more equitable distribution, or 'cleaning profit chains', would both be justified and highly worthwhile, without job loss. Investing part of this homegrown finance in further securing lawful and rational management of exhaustible forest-based resources has several additional economic, social and environmental benefits, including for forest-dependent citizens. Society awareness of current revenue ratios, REDD+ income losses, and potential returns of interventions may add helpful (i.e. economic, domestic) motivation for forest governance change in sovereign countries.

Weak law enforcement, prevailing across the tropics, enhances lopsided sharing, and linked political leverage could undermine plans that would interfere with private income streams, e.g. rural social development, tenure, forest/biodiversity conservation. Interventions may therefore additionally enhance these sectors' performances. Assessing and cleaning private profit chains may more generally have potential for REDD+ and global climate change mitigation goals, along with its many associated social and environmental co-benefits.

1. Introduction

The 2015 Conference of the Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris saw a renewed global-level acceptance of the need to act on human-driven climate change. Nearly 200 member countries of the UNFCCC pledged to collectively reduce carbon dioxide emissions to a level sufficient to restrict temperature increases to less than 2 °C above pre-industrial levels (UNFCCC, 2015a). A recent

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UN-invited Special Report, conveying the latest scientific knowledge, showed the severe global impacts of a 1.5 °C increase (IPCC, 2018). The Paris agreement emphasised the importance of the reduction of emissions from deforestation and forest degradation and enhancing carbon stocks (REDD+) program as a strong mitigation option (*Ibid.* Article 5). This has recently been reiterated by the Katowice Declaration (UNFCCC, 2018a).

REDD+ is designed to provide financial compensation to partner countries for reducing carbon emissions from deforestation and degradation (Angelsen et al., 2009: 2). Tropical deforestation and degradation produce about 10% of global anthropogenic carbon emissions (4.8 of 49 $GtCO_2.yr^{-1}$, Pan et al., 2011: 988; Intergovernmental Panel on Climate Change (IPCC), 2014: 6) or the equivalent of 9 billion barrels of crude oil per year (Carnegie Endowment for International Peace, 2015). The Paris Agreement, coupled with the urgency for global carbon dioxide (CO_2) reductions (Carbon Tracker Initiative et al., 2017: 4; CPLC, 2017: 6; UNFCCC, 2018a), have provided additional confidence to recipient and donor countries to continue their investment in national REDD+ readiness and implementation activities. By the end of 2018, for example, 34 of 58 partner countries, in comparison to six in 2015, had submitted a forest reference emission level (FREL) proposal to the United Nations (UN) (UNFCCC, 2018b).

As a program for reducing CO_2 emissions, REDD+ is ultimately geared towards rewarding climate change mitigation activities at national, or jurisdictional levels (Angelsen et al., 2009: xi; Eliasch, 2008: xvi; Meridian Institute, 2011: ii; UNFCCC, 2016, 2018b), with many REDD+ projects having been implemented as demonstration and learning experiences (Angelsen, 2016: 2). At the implementation stage, REDD+ payment to countries would be based on the demonstrated annual performance against the country-specific crediting baseline or reference level, which is derived from a country's historical emission levels (Meridian Institute, 2011, Angelsen, 2016). For this, REDD+ requires that countries develop the capacity to i) accurately calculate historical CO_2 emissions from deforestation and degradation activities (to calculate the reference emission level, i.e. the hitherto normal annual forest emissions), ii) provide accurate data on carbon density variation in forests across the country (total standing carbon stock), and iii) monitor and annually report, at a national level and in an externally verifiable manner, forest emissions from both deforestation and degradation to calculate performance against the baseline (Angelsen et al., 2009; Government of Guyana [GoG] 2015a: 8–15; Meridian Institute, 2011; Strassburg et al., 2009: 266–67). By the end of 2015, most partner countries did not have the capacity to provide the required information (UNFCCC 2015b) to obtain REDD+-related payments. Therefore experiences accounted for in the literature by this time on the program's performance were based on projects and subnational levels initiatives (Sills et al., 2014; Fisher et al., 2015; Sunderlin et al., 2018). Consequently, potential REDD+ earnings at national levels have remained obscure.

Partner countries' challenge in meeting the stringent requirements to report on the performance of their carbon stocks is compounded by the assertion that REDD+-related revenue may be unable to compete with those derived from profitable deforestation-based industries (Butler et al., 2009: 67; Pacheco et al., 2012: 65–66; Turnhout et al., 2016: 3; Wong et al., 2016: 4–5). In fact, Boucher (2015: 554) claimed that at the global level REDD+ funding is, and will likely remain, insignificant (5.4%) compared to the financial benefits attributed to the four major industries driving tropical deforestation (beef, soybeans, palm oil, and wood products). While such estimates epitomize the challenge facing REDD+ partner countries, they raise questions as to whether developing countries should use their forests for revenue accruing to the private sector or on revenue accruing to the country. Our

paper aims to shed light on public–private revenue distributions for the two main drivers of forest emissions in the South-American country of Guyana (alluvial gold and diamond mining and selective logging), and determine how REDD+ revenue would compare. If REDD+ is indeed uncompetitive, then current calls for forest governance change based on ethical arguments, while justified, may in practice have little positive effect on deforestation and indigenous tenure rights on the ground. This would be even more so since current land use is typically backed by powerful interests. In addition, the lack of REDD+ funds (stemming from continued international delay in making emission reductions obligatory in spite of dire science-based warnings), is neither helpful for REDD+'s cause in developing countries. Two prominent recent evaluations of global research on REDD+ progress appear to confirm the above lines of argument (Angelsen et al., 2018: xxi-xxiv; Duchelle et al 2018:1). Duchelle et al., for example, make the multiple significant current and future values of tropical forests and the impacts of deforestation abundantly clear. Yet they concur that 'REDD+' as well as 'new coalitions calling for changes in forest governance' have so far failed to reverse deforestation, and point out in their conclusions that 'deforestation and forest degradation […] are deeply rooted in powerful business-as-usual interests. Our findings suggest there may be a thus far unexplored route for a viable, perhaps even powerful, mechanism to move REDD+ forward.

In 2015, Guyana became the first country to provide comprehensive reference level details in its FREL submission to the UNFCCC, i.e. nationwide and including forest degradation emissions over a twelve year historical period (GoG, 2015a; UNFCCC, 2015b). The submission has been approved by the UN's technical assessment (UNFCCC, 2015c), and includes justification of the proposed steps to calculate annual performance payments. The FREL submission allows for the calculation of financial rewards Guyana can receive from REDD+ under different emissions scenarios. These data provide an opportunity to estimate the financial contribution of REDD+ to the national budget, and to make comparisons with state returns from commercial forest uses, at country level and on a hectare basis.

The FREL submission also permits an assessment of another major REDD+ concern, increased land grabbing. Land grabbing by elites or a 'resource rush' is expected "when REDD+ gives value to a new commodity (forest carbon)" (Sunderlin et al., 2014: 38; Larson et al., 2013; Loft et al., 2015: 1033). This could endanger the livelihoods of forest-dependent peoples that lack legal tenure to their traditional forests. The specific objectives in this paper are to:

a) Examine how Guyana's UN-approved national REDD+ program functions, consider how it differs from REDD+ projects, and whether national REDD+ incentivizes land grabbing.
b) Assess the potential financial significance of REDD+ for the national budget, and compare it to state revenue from logging and gold and diamond mining, before and after including REDD+ opportunity costs of these sectors,
c) Estimate cumulative private and state net revenue shares per hectare, based on legally declared amounts and on estimates of under declaration and inefficient gold recovery, and
d) Discuss the potential for improving the owner's share of natural resources, or 'cleaning profit chains'.

Our paper contributes to global REDD+ discussions, first, by showing for the first time how '*national* REDD+' would financially perform from the perspective of the owner of the natural resources. Second, by drawing attention to very skewed private–public net revenue ratios of natural resources, and the probable consequences of this relationship for rural development, REDD+,

and conservation efforts. And third, by suggesting that transparency in net revenue distributions among resource stakeholders allows for national discussion on equitable corrections through forest governance change in sovereign countries.

Implications of national REDD+ for forest-dependent indigenous communities in Guyana and the wider tropics, including land tenure, were explored in Overman et al. (2018).

2. Materials and methods

2.1. Guyana's national REDD+ program

Background information on Guyana and its development of REDD+ is presented in Supplementary Note S1. Guyana's FREL submission to the UN-REDD programme (GoG, 2015a) contains the averages of nationwide deforestation and degradation emissions, timber production and carbon stock data of its forests over a twelve year historic period (2001–2012). The submission is based on detailed robust analysis, applying IPCC guidelines, with technical guidance from WINROCK International, and annual emission data verified by a third party consulting firm (Det Norske Veritas). The FREL submission has been technically approved by the UN (UNFCCC, 2015c), and states that Guyana's mean annual CO_2 emission rate during its reporting period (2001–2012) was 0.049% (GoG, 2015a). This is the portion of its total national forest carbon stock, in CO_2 equivalents, emitted per year through deforestation and forest degradation, and is one of the lowest emission rates in the world (Harris et al., 2018: 28). The main drivers of forest emissions were the mining and logging sectors, contributing 49% and 42% respectively to the annual total of 9.4 million metric tons of CO_2. The remaining emissions came from agriculture (7%) and infrastructure development (2%) (GoG, 2015a). Emissions from deforestation are monitored by countrywide high-resolution satellite imagery (RapidEye, 5 m resolution), reported annually, and externally verified (Guyana Forestry Commission [GFC] and INDUFOR, 2015). Emissions from forest degradation related to logging are currently calculated from annual timber harvest records, combined with emission factors from detailed field studies in six timber producing countries including Guyana on extracted volume, incidental damage and residues, and infrastructural damage (Pearson et al., 2014). Afforestation and reforestation are not yet addressed (GoG, 2015a), while recovery after logging is a natural process hence does not pass REDD+'s additionality criterion (i.e., the CO_2 removal would not have happened without human effort/intervention). These three forms of carbon sequestration (or 'removal') are therefore not considered in this paper.

In its technically approved FREL submission (UNFCCC, 2015c) Guyana adopted the Combined Incentive approach of Strassburg et al. (2009) to develop a payment model. It is among the best proposed models that, importantly, provides the most financial incentive to *all* tropical forest nations to join REDD+ (Strassburg et al., 2009; May-Tobin, 2011) by rewarding both reductions in emissions and maintenance of forest cover. The model seeks to avoid international leakage of emissions by providing an incentive for High Forest Low Deforestation (HFLD, Da Fonseca et al., 2007) countries such as Guyana to join REDD+ programs to maintain low emissions levels. If payments were only based on emission reductions, developing countries with historically low forest emission rates and large forest cover (HFLD countries) would have little incentive to join REDD+. Instead, they could be persuaded to accept offers from forest based industries that come under pressure in other REDD+ countries to operate in their (HFLD) forest, resulting in not a reduction but a relocation or international 'leakage' of emissions, thus invalidating the REDD+ credits of the non-HFLD

country (Strassburg et al., 2009). Based on Guyana's submission (GoG, 2015a), potential REDD+ revenue can be calculated as:

$$
\begin{aligned}
\text{Annual Revenue in Year}_x = {} & (\text{Reference Emission Level} \\
& - \text{Actual Emission Level in Yr}_x) \\
& \times \text{Guyana's forest } CO_2 \text{ stock in Yr}_{x-1} \\
& \times \text{Carbon price} \quad\quad\quad (1)
\end{aligned}
$$

Guyana's approved reference emission level is 0.242%, which is the 'combined average' of the mean pan-tropical historical emission rate (0.435%, adapted from Baccini et al., 2012) and Guyana's mean historical emission rate of 0.049% (GoG, 2015a; UNFCCC, 2015c). The reference level marks the tons of CO_2 against which Guyana's annual emissions are compared each year (0.242% of its forest CO_2 stock, i.e. C-stock times the C-to-CO_2 conversion factor (44/12)). The difference is the rate at which Guyana has avoided emissions, which is multiplied by the forest stock and by the carbon price to arrive at the amount of revenue earned that year (Eq. (1); see Supplementary Note S2 for more details). Notable is that national REDD+ is not subject to the structural difficulties of project-level REDD+ initiatives (setting reference levels, national leakage, permanence, Fisher et al., 2015), since each country develops its reference level based on historical countrywide forest emissions, which serves as the baseline of normal emissions, per year.

Guyana reported that its forests contain an average 284 metric tons of carbon (tC, or mega gram, Mg) per hectare (aboveground and belowground living biomass pools, range 239–331, GoG, 2015a), and it uses the interim carbon price set by Brazil's Amazon Fund in 2009 to determine revenue (US$5 per tCO_2, Joint Concept Note, 2015). We adopted the same price in our analysis, and briefly evaluate effects of higher carbon prices which are deemed urgently needed by prominent sources to meet the Paris temperature target (CPLC, 2017; Carbon Tracker et al., 2017).

2.2. Variables and data

In order to provide the country-level view into how national REDD+ compares financially with commercial land uses (from the perspective of the Guyanese society) data were obtained from a number of public sources. The figures on emissions and commodity yields used here are nationwide averages covering more than a decade (2001–2012). Hence these data encompass variance in localities, differences in technology and efficiencies within land use sectors, including possible changes in these values over the observation period. This allows for a fairly robust comparison of land uses at country-level. We start with gross returns (Tables 1 and 2), then estimate net returns for both private and public stakeholders (Table 3).

Only land uses that are accompanied by significant annual deforestation or degradation are included in the analysis. Guyana's forest degradation emissions were based solely on those from logging (GoG, 2015a). Other degradation sources such as shifting cultivation and forest fires are monitored, but by area so far, while emission factors are being developed (to calculate annual CO_2 emissions; GFC & INDUFOR, 2015). Reported deforestation emissions from mining were not further disaggregated by commodity. Several minerals and metals are mined in Guyana, yet the most relevant by export value are gold, bauxite and diamonds (Bank of Guyana, 2015). During the historic period (2001–2012) one large scale goldmine was operational until 2005. Public satellite imagery shows that the, largely one-off, deforestation for this open pit mine was comparatively small, and moreover occurred before 1993 (Thomas, 2009). Its declared gold was omitted from analysis.

We also excluded bauxite from the analysis. While we were unable to find quantitative annual deforestation data for bauxite, anecdotal evidence suggests bauxite mining in Guyana to have

been largely confined to pit mining at two sites (Linden and Kwakwani), that have been operational since many decades but in decline for some decades (Colchester, 1998). Satellite imagery suggests annual deforestation during 2001–2012 may therefore have been small compared to the overall mining deforestation during this period (~55,000 ha, GoG, 2015a).

Most mining deforestation therefore stems from small/medium scale gold and diamond mining, which is largely alluvial, although rock mining and river dredge mining also occurs to an unspecified extent. The two latter types of gold mining contributed to annual declared gold but not to annual deforestation, and would therefore lead to a slight overestimation of the average yield per deforested hectare. The declared annual volumes of gold and diamonds are included in this analysis, with diamonds on average worth ~10% of the gold export value (Bank of Guyana, 2015). From hereon, 'gold' and 'gold mining' are taken to include diamonds.

We use the variable 'state revenue' (further explained in Sections 2.3–2.5) for three reasons. First, state revenue much more reflects real state earnings of a sector than for example 'GDP' (gross domestic product) or 'foreign exchange earnings'. Particularly in the case of gold, GDP or 'export value' are distortive indicators for our purpose. Since Guyana charges 7% (5% royalty + 2% tax) when buying the private miner's gold and diamonds, this implies 93% of these commodities' GDP value is bought with state funds. Second, state revenue allows for the comparison of state returns from different types of commercial forest use (CFU), and against forgone revenue from these sectors' forest emissions under a national REDD+ program. Third, state revenue can be compared with estimates of private returns to provide insights into how overall revenue of the resource is divided between the owner and the private sector commodity chain.

State revenue does not comprise all benefits of CFU sectors, as a country's economy additionally benefits from employment and financial inputs from salaries and investments, and from materials and services the sector uses (see Section 2.4 for more details). Although there is logic in the reverse as well; there would be no gold and wood production and resulting private profit without the country's workers and services. In addition, governments can forego significant revenue from sector concessions and subsidies (e.g., Ministry of Natural Resources and Environment, 2015; McFarland et al., 2015; UN-REDD, 2016), and it has the onus of control- and administrative costs of the sectors. These aspects are however not relevant for our purpose which focuses on net profits of CFU, which arise as a product of the labor, i.e. *after* production and labor costs are paid.

We estimated cumulative net profits of all links in the commodity supply chain (i.e., the 'chain' of agents involved in moving resources from supplier to customer) and not only of the first 'ground-level' link. This estimate was used because remote rural settings often have difficult access, and minimal law enforcement and income alternatives, which may force small 'primary producers' (ground links) to accept marginal profits when compared to profits from other links further along the supply chain. Such a scenario can produce a biased view of overall profits on the natural resource.

2.2.1. Data

To determine attributes of the supply chains of gold and timber production, we drew on a decade of nationwide official government data (e.g., state revenue and private profit on declared gold, state revenue of wood, rates of deforestation and degradation, Bank of Guyana, 2015, GFC, 2013, GoG, 2015a, Guyana Gold Board, cited by Thomas 2009). A general lack of public data on private (and sometimes government) net costs and profits (respectively 'revenue') implied that for some data we had to rely on single estimates, although sourced from experienced professionals (e.g.,

commodity chain analysis of logging profits (Bulkan, 2012, Table 3), overall and cut-off gold grades (Swiecki, 2011, see Supplementary Note S3), gold production costs (Guyana Gold Board, cited by Thomas, 2009), or stick to gross estimates (state revenue of gold and REDD+ earnings). On two occasions where no data existed, we made assumptions to provide insights (average gold grade of Guyana mining grounds, and average recovery efficiency of mining operations, see Supplementary Note S3). In Section 4.3 we discuss the limitations and merits of this approach.

2.3. State revenue from national REDD+

We utilized Eq. (1) to compute national gross REDD+ revenue under different emission scenarios, including Guyana's most recent (2014) documented emissions rate (GFC and INDUFOR, 2015; GoG, 2015a). 'Gross' revenue implies excluding all running costs of a national REDD+ mechanism (e.g., for monitoring emissions, reporting, administration), as estimates of these costs were not available for Guyana. For comparability, we used the gross income of the logging and gold mining sector, and note that the proportional costs of REDD+ and of these sectors may differ. We derived total state revenue from the government's 2015 Budget presentation (GoG, 2015b), which is corroborated by World Factbook figures (CIA, 2014).

2.4. State revenue from the logging and gold mining sectors

State funds generated by the timber and gold mining sectors can be divided into direct income (royalty, acreage, license fees and export commission, fines), and indirect income (taxes on salaries and company incomes). For small/medium scale gold miners (processing up to 200 respectively, 1000 m^3 soil per day), a 2% tax on their gold sales is derived as income tax. Here we focus on direct state revenue as no sectoral tax revenue information was available in the public domain to aid computations. In addition, others (e.g., Ram, 2011; Thomas, 2012; Wilburg, 2014) have suggested that indirect (i.e. theoretical) tax estimates may bear little relation to reality in Guyana and hence our computations did not include this element.

2.4.1. Wood

The GFC (Guyana Forestry Commission) is the government body that handles all forestry sector activities and finances. Gross state revenue from commercial logging was calculated as the average gross income of the GFC over 2004–2012, as published in a series of Annual Reports released in 2013 (GFC, 2013), converted to US dollars (Fxtop, 2015). These reports also give the GFC's net revenue, which we used for a comparison of net revenues between the state and private sector (Table 3). The REDD+ opportunity costs of the logging sector were calculated by multiplying mean annual forest degradation emissions (GoG, 2015a) by the interim price per tCO$_2$ set by Brazil's Amazon Fund (US$5, Joint Concept Note, 2015).

2.4.2. Gold

Neither the mining oversight body, the Guyana Geology and Mines Commission (GGMC), nor the body that buys gold, the Guyana Gold Board (GGB), produced public financial statements over 2001–2012. Government gold mining revenues were instead estimated from royalty (5%) and tax (2%) on declared amounts of gold between 2001 and 2012 (Bank of Guyana, 2015), multiplied by the mean annual gold price of the London Gold Bullion Market (Kitco, 2016). Added to the gold revenue was an indirect estimate of rental revenue from mining permits, based on a value of $2.47 per ha per year (GGMC, 2016), and the total permit area during this period sourced from various publications (Colchester et al., 2002; Guyana Times, 2015; Stabroek News, 2010; Thomas, 2009). Our

estimate of state revenue from gold corresponded with a value presented by the GGMC to the United Nations Environmental Programme (GGMC, 2010). The REDD+ opportunity costs of mining were calculated by multiplying mean deforestation emissions of mining (GoG, 2015a) by US $5.

2.5. Net revenues of state and private sectors

2.5.1. Wood

Net state revenue from logging was derived from available GFC annual reports (2004–2012, GFC, 2013). Net private profit of the logging sector was sourced from Bulkan (2012) who examined the net present value per cubic meter of high-quality Wamara timber, *Swartzia leiocalycina*, along the logging value chain from extraction point to end use as flooring in China and Europe. Wamara is a good representative average species. Its cubic meter price of $188 falls in the middle of the range, $110–$263, for exported log species (species with >1000 $m^3.yr^{-1}$ exported) (GFC, 2016). In 2010 it was the number two species in total export value, after Purpleheart (*Peltogyne* ssp.) and before Mora (*Mora excelsa*). Since 2010 it has become, by a large margin, the number one species in log export value (GFC, 2016).

2.5.2. Gold

Net State revenue of gold could not be determined due to lack of data on running costs of the GGMC and GGB (recent audit reports of these institutes were not publicly available). Net profit of small/medium-scale gold mining was derived from the value of the declared volume of gold by subtracting 7% state taxes, the gold production cost estimated by the GGB (Thomas, 2009) and 10% commission to permit holders (Lowe, 2006).

2.5.3. Under declaration

Proportions of illegal extraction of wood were sourced from estimates by the World Bank, CIFOR/Iwokrama and the Government of Guyana (Clarke, 2006; GoG, 2015c; Trevin and Nasi, 2009). Amounts of illegal and inefficient gold extraction was estimated from in-depth sector interviews and research (Falloon, 2001; Harvard Law School, 2007; Thomas, 2009) and data from a mining expert and geological engineer in Guyana (Swiecki, 2011), sustained by a simple assessment of return-risk ratios driving human motivation (details in Supplementary Note S3).

3. Results

Using Eq. (1) and Guyana's carbon emission and stock data (GoG, 2015a:6), we found that gross national REDD+ revenue would at maximum be $231.5 million per year under a hypothetical emission rate of zero percent (($0.00242 – 0.000$) * 19,134,623,287 tCO_2 * $5, Table 1). Using the most recent available emission rate of 0.065% in 2014 (GFC & INDUFOR, 2015), REDD+ earnings would be $169.3 million per year. Guyana's total state revenue was $700.7 million in 2014 (GoG, 2015b, exchange rate US$1 = G$206.50). This implies REDD+ would increase

Guyana's total state revenue by 24.2% under current (2014) emission levels.

The timber sector yielded a mean annual $3.7 million in state revenue between 2004 and 2012 (range $2.7–$4.7 million, GFC, 2013), and emitted an annual average of 3.9 million tCO_2 (Table 2). Under REDD+, the sector's emissions would cost the Government of Guyana $19.7 million per year (emissions * $5) in foregone revenue.

State revenue from gold mining from 2001 to 2012 averaged $15.8 million from declared gold (range $1.7–51.2 million) and $1.8 million from declared diamonds (range 0.5–3.4 million, Bank of Guyana, 2015), plus an estimated average $3 million in rental income from permits, for a total of $20.6 million (Table 2). The sector's opportunity costs under REDD+ would surpass this income by 11.2% ($22.9 million). REDD+'s contribution to the annual budget of this country ($169.3M, Table 1) would be seven times larger than the contributions of the gold, diamonds and logging sectors combined ($24.3M, Table 2).

Estimates of net profit to the private sector as well as revenue to the government from the logging and gold mining sectors, using publicly available data, are provided in Table 3, with calculations presented in the footnotes. Based on interviews with stakeholders along the logging supply chain regarding their sale price and incurred costs, Bulkan (2012) estimated potential profits of $95 m^{-3} for the chain segment 'extraction point hinterland to the coastal capital city of Guyana, Georgetown'. From 'Georgetown to Free On Board (FOB) a ship in Georgetown's harbor' another $160 m^{-3} profit is realized, with $333 m^{-3} more profit in 'shipment from Guyana to China', and lastly, assuming a third profit margin, $605 m^{-3} profit for flooring manufacturers (derived from Bulkan, 2012). This makes the cumulative private sector profit along the supply chain (from forest road to retailer) $1,191 m^{-3} (Table 3). The net state revenue of hardwood for Guyanese society, in turn, was $1.04 m^{-3} ($6.11 m^{-3} gross, minus 83% to run the forestry regulatory agency, GFC, 2013). Additionally under REDD+, logging emissions will cost the State 43 times more in foregone revenue (Table 3). In terms of net state yield and overall employment in the timber sector (22,561 jobs, GFC, 2014), Guyana's forests have been logged yielding national society $13 per hectare and employing 0.5 persons. Under REDD+, the logging sector will cost Guyana $547 per hectare in state revenue (560–13, Table 3).

Gold production costs depend on several variables, and can range from around $1,250 per troy ounce (31.1 g) according to the Guyana Gold and Diamond Miners Association (GGDMA, a local small – and medium scale miners' organization) (Guyana Times, 2014) to just $77 per ounce by an efficient professional operation (Swiecki, 2011, see Supplementary Note S3). We use the Guyana Gold Board's production cost estimate of $240–$300 per ounce cited by Thomas (2009). After 7% State taxes, 10% commission for the permit holder, and assuming no exploration costs (Lowe 2006), using gold production levels declared to the government, we estimated that the mining sector earned a mean $33,400 net profit per hectare over 2001–2012 (Table 3). This is 7.5 times the $4,475 gross state revenue. Under REDD+, Guyana would forego

Table 1
Gross annual REDD+ revenue for Guyana under different emission scenarios (using Eq. (1) [see Section 2.1] and US$5 per tCO_2, GoG, 2015a).

Emission scenario	Emission rate (%)	Annual revenue (million US$)	Annual avoided emissions (million tCO_2)
National historical rate (2001–2012)	0.049	184.6	36.9
Emissions in 2014 (most recent data) [a]	0.065	169.3	34.0
No emissions	0.000	231.5	46.3
Total State revenue in 2014		700.7	

[a] Most recently published: 0.048% for the year 2017 (GFC & INDUFOR, 2018).

Table 2
Mean gross state revenue, emissions and REDD+ opportunity costs per year (2001–2012) of the timber and gold mining sectors in Guyana (at US$5 per tCO_2).

Sector	State revenue (million US$.yr^{-1})	Emissions (million tCO_2.yr^{-1})[a]	REDD + opportunity cost (million US$.yr^{-1})[b]
Timber	3.7[c]	3.9	19.7
Gold mining	20.6[d]	4.6	22.9

[a] Mean over the historical period 2001 – 2012 (GoG, 2015a).
[b] Mean annual emissions * $5 (GoG, 2015a).
[c] Mean over 2004–2012 (GFC, 2013).
[d] 7% tax over the average declared gold and diamond production during 2001–2012 ($15.8 M + $1.8 M), plus an estimate of rental revenue ($3M. See Methods for further explanation and sources).

Table 3
Private and State net revenue estimates and REDD+ costs of the timber and gold mining sectors in Guyana, based on declared amounts (round US$ figures, $5 per tCO_2).

Sector	Unit	Profit private sector	State revenue	REDD + opportunity costs	Forest impacted (ha.yr^{-1})
Timber	Cubic meter (logs)	250[a] 950[b]	1[c]	43[d]	
	Logged hectare[e]	3,250 12,350	13	560	46,000[f]
Gold mining	Deforested hectare	33,400[g,*]	4,475[h]	5,200[i]	4,600[j]

[a,b] Potential profit on wamara hardwood, *Swartzia leiocalycina*, for national (a) and international (b) sections of the supply chain: a) extraction hinterland to 'Free on Board' (FOB) in harbor of coastal capital Georgetown, and b) international shipping to flooring use in China, Europe (Bulkan, 2012).
[c] $0.6 M/593,641 m^3 (mean net GFC revenue/mean annual wood production, (GFC, 2013, GoG 2015a).
[d] (30.3/13) * (44/12) * $5 (tC logging emissions ha^{-1}/m^3 extracted ha^{-1} (Pearson et al. 2014)). '44/12' is the C—CO_2 conversion factor.
[e] 13 m^3.ha^{-1} (mean extracted volume per ha, Pearson et al., 2014).
[f] 593,641 m^3.yr^{-1}/13 m^3.ha^{-1} (mean annual wood production/m^3 extracted ha^{-1}, (GoG 2015a, Pearson et al. 2014).
[g] $154.1 M/4,613 ha (Net private profit/mean mining deforestation yr^{-1}. Net profit is weighted mean value of annually declared gold – 10% permit commission – 7% State taxes – $270 oz^{-1} production costs. 1 oz. (troy ounce) = 31.1 g (Bank of Guyana, 2015, GoG, 2015a, Lowe, 2006, Thomas, 2009).
[*] See Section 4.3 for a private profit estimate that includes an estimate of under declaration and inefficiency.
[h] $20.6 M/4,613 ha.yr^{-1} (mean State revenue/deforested hectares, (GoG 2015a, Table 2). Note this is *gross* State revenue, i.e. the (unknown) running costs of the GGMC and GGB are to be subtracted from this amount.
[i] 283.7 tC.ha^{-1} * (44/12) * $5 (mean C-stock per ha, GoG, 2015a).
[j] 4,613 ha (mean mining deforestation yr^{-1}, GoG, 2015a).

$5,200 per hectare due to deforestation emissions. In terms of state yield and overall jobs attributed to the mining industry (13,000 jobs, GGMC 2010), Guyanese forests have been cleared for $4,475 (gross) per hectare employing 2.8 persons. Under REDD+, gold mining will cost Guyana well over $725 per hectare in state revenue (4,475–5,200, Table 3) at a $5 carbon price.

4. Discussion

4.1. REDD+ competitiveness

Contrary to assertions that REDD+ is and will likely remain uncompetitive against current economic land uses (Boucher, 2015; Butler et al., 2009; Pacheco et al., 2012; Turnhout et al., 2016; Wong et al., 2016), our analysis indicates that Guyana's national REDD+ program would add nearly a quarter more revenue to the national budget, outperforming the combined budget contributions of the gold and timber sectors sevenfold. This is partially explained by Guyana's HFLD character (cf. Eq. (1)). However, we found the nation would also forego more REDD+ revenue than it earns on a hectare basis, even from high value forest commodities and at a modest preliminary carbon price (Section 4.4.2). This discovery contradicts concerns about REDD+ being unable to compete financially against deforestation activities (Boucher, 2015). We do not suggest that REDD+ can out-compete private profits (but see Section 4.1.1), but rather that it can out-compete sector returns received by the owner of the natural resources, in this case the state representing Guyanese society. We also discovered highly skewed net benefit sharing between the private sector (favored) and the state from logging and gold mining. This sharing ratio is much further exacerbated when including estimates of under declaration and inefficiency in the gold sector (Section 4.3).

4.1.1. Carbon density

Besides its HFLD character, REDD+'s competitiveness in Guyana also benefits from the comparatively high carbon density of its forests (284 tC.ha^{-1}, GoG, 2015a): around double that reported by other Amazon countries such as Brazil, Colombia, and Ecuador (UNFCCC, 2018b), but in line with a southwest to northeast trend of increasing tree wood densities across the Amazon basin (e.g., Ter Steege et al., 2006). This finding implies Guyana will receive about twice as much revenue per avoided hectare of deforestation as these other countries. However, if carbon prices increase 8–16 fold, as was recently concluded to be necessary by 2020 to meet the Paris temperature objective (CPLC, 2017; Carbon Tracker et al., 2017), this would more than compensate twofold lower carbon densities (further discussed in Section 4.4.2). Such carbon prices ($40–80, or higher) would place serious economic pressure on CFU in any natural forest: clearing even low carbon forest of e.g. 100 tC.ha^{-1} would cost a country ~$15,000–30,000 per hectare in forgone REDD+ revenue (100 * 44/12 * $40–80). Higher carbon prices may therefore make CFU economically prohibitive for the country. Agricultural CFUs may be pushed to lower carbon or already degraded landscapes, which has been shown economically viable (Strassburg et al., 2014), or towards 'climate-smart agriculture' (sustainable intensification of agricultural production, Ngoma et al., 2018).

4.2. Land grabbing

Guyana's UN-approved model (Eq. (1)) produces negligible annual rent for owning a hectare of forest, hence should provide little incentive for land grabbing. The factor '(REL – AEL)' in Eq. (1) implies that if there are no emission reductions in a given year, (REL = AEL), this factor becomes zero and no revenue is made on

any hectare of standing forest. If, for example, a country's REL is near the global average, 0.4%, and its AEL in a given year is 10% below that (0.36%), then revenue made for a hectare of forest (of say 200 tC) is given by: $[0.0040-0.0036] * 200 * (44/12) * \$5 = \$1.47 \text{ ha}^{-1}$. Even an ambitious 50% reduction (AEL = 0.2% in our example) would yield a mere $\$7.33 \text{ ha}^{-1}$ forest rent that year. This is unlikely to become a motivation for land grabbing since damaging that forest at any time will cost the owner (or the State) $5,200 when cleared, or $560 when logged in forgone REDD+ revenue at a $5 carbon price in Guyana (Table 3). National REDD+ appears not to 'put value' on standing forest (in terms of annual interest), but financial penalties (lost income) on forest damages (clearing or degradation). This is because standing forest does not mitigate climate change. Its natural sequestration is non-additional ('without human effort'), hence not rewarded. Standing forest is valued indirectly, as it is the denominator of AEL, and a multiplication factor ('forest carbon stock') in Eq. (1). Civil vigilance on government REDD+ decisions will however remain warranted as systems could be manipulated to unequally benefit a minority in the absence of sufficient oversight and engagement by civil society (cf current forest commodities, as shown in this paper). A Free Prior Informed Consent (FPIC) process for national society on REDD+ may very well be beneficial in this regard.

Governments should also take measures against pre-REDD+ land grabbing for CFU purposes (acquire cheap now, convert later), as the country will incur foregone revenue costs upon conversion. By this logic it appears REDD+ is not inherently 'bad' for tropical forests and its inhabitants, but it can be appropriated towards unequal sharing under poor oversight conditions.

4.3. Under declaration and inefficiency

In the context of our analysis of private-state revenue sharing, the implications of under declaration of products should be considered. The volume of wood that goes undetected through the system in Guyana is estimated at 2–15% (Clarke, 2006; GoG, 2015c; Trevin and Nasi, 2009), and at 25–400% for the alluvial gold sector; this amounts to a quarter to four times the declared amount (Falloon, 2001, Harvard Law School, 2007; Thomas, 2009). Exact estimates of under-declared amounts are by nature impossible, but in Supplementary Note S3 we suggest that incentives to under-declare along the supply chain, combined with inefficient gold recovery, may well have resulted in Guyana having lost revenue from gold volumes beyond four times what was declared during 2001–2012. Based on our indicative estimate (479%), missed state revenue may have averaged $84.5 million per year (4.79 * $17.6 M, Table 2, peaking to $248 M in 2012). It implies that average net private profit over this period may have been $290,800 per hectare (Suppl. Note S3), i.e. not 7.5x but 65x more than the gross revenue for the state ($4,475, Table 3).

4.4. The potential of cleaning profit chains

Our estimates indicate extreme levels of discrepancy in net benefit distribution of natural resources between state and private sector supply chains, with net state shares of <1.5% for gold, and 0.08% for wood (derived from $4,475/[$290,800 + $4,475] for gold (Section 4.3), and $1/$1,200 for wood (Table 3)). Despite uncertainty around the exact values of net private gains for lack of public figures, the observed discrepancies (approximately a hundred, respectively, a thousand fold difference) appear so extreme that, first, small omissions and errors in data are unlikely to alter such ratios substantially, and second that at a minimum it would warrant further research. We stress that these ratios are initial estimates and can be recalculated in the future as more comprehensive data become publicly available. As it stands,

Guyana as a country appears to receive little net revenue from the exploitation of its forest-based natural resources, and our estimates appear to suggest that Guyana can adjust current policy to improve the revenue earned from the main drivers of deforestation and degradation (Section 4.4.1).

Further, although the notion of gold smuggling and low state proceeds of logging are widely known and reported in Guyanese news media (e.g., Kaieteur News, 2014; Stabroek News, 2015), ours are the first reasonably plausible countrywide estimates of how overall net revenue for the two main forest-based resources has been divided between the 750,000 owners (Guyana's population) and the company owners or individuals representing the links of the supply chains. This may aid economic motivation for national discussion on forest governance change.

Our findings have further implications for REDD+. At a minimum, gold and wood commodity chains appear able to contribute in bearing the costs of emission reduction measures and enhanced forest rehabilitation (cleaning supply chains), in lieu of claiming the REDD+ credits as compensation. The emphasis is on commodity chains as a whole and not just the first link at the ground level.

In addition, the modest overall state revenue and employment figures per hectare of CFU (logging $13 ha^{-1}, 0.5 jobs, gold mining $4,475 ha^{-1} gross, 2.8 jobs) should also, from the government's perspective, help ease land use conflicts between CFU and forest-dependent peoples (FDP) on titled or customary lands. This is primarily the case because CFUs are typically associated with large long-term damage to livelihoods and social disruption in communities of the first inhabitants, next to environmental damage (Colchester et al., 2002). Declining or revoking commercial permits on FDP-lands would simultaneously demonstrate adherence to mandatory REDD+ social safeguards, i.e. respecting indigenous rights (more in Overman et al., 2018).

4.4.1. Improving the owner's share, and employment

The observed small net state yields on these commodities additionally indicate that government interventions towards more equitable distribution, or 'cleaning profit chains', are both well-justified and would be well-worth the effort. Just a 1% share increase (i.e. from the current ∼1%, to 2%) would double state revenue from this sector annually. Redistributing excessive profits more equitably amongst commodity chain links and the resource owner, society, could reduce pressure on forests on three fronts; from ground-links (better margin, if this induced more clearance), from higher-up links (smaller profitability), and by the state (better control).

It is beyond the scope of this paper to elaborate on all possible interventions, as these will be dependent on country-specific circumstances, but we offer some general suggestions. Interventions in Guyana's gold sector could best focus on reliable law enforcement and professionalization of the sector (Supplementary Note S3). Simply increasing royalty and licensing rates based on findings such as ours, is unlikely an adequate option as it runs the risk of further cutting margins of smaller and less professional ground-links (who struggled at a $1250 gold price). It would result in higher need as well as higher profitability of smuggling, or unemployment, while leaving links with much higher margins, as well as the large smuggling and spillage problems unaltered.

For gold, the commodity's end value is attained within country boundaries. But even the international profits on wood may not be out of reach if, to avoid 'logging company leakage', producer countries could come to a collective agreement of increasing FOB prices on the globally highly demanded resource leaving their shores, and set proportional export commission rates. Price competition with the globally high volumes of illegally sourced wood (Nelleman & INTERPOL, 2012) may soon become significantly reduced through rapid advances in remote sensing and drone technology towards

monitoring of individual tree gaps in logging concessions, and linking these to log volume (e.g. 30 cm resolution, DigitalGlobe, 2017, Mitchell, 2014, Pearson et al., 2014, 2018; Planet, 2017; Reiche et al. 2013). With net timber profits so lopsided and the REDD+ costs of logging so high (Table 3), producer countries might also consider passing some of the burden of proof of operating legally (or its costs) to the logging commodity chain.

Interventions towards more equitable revenue sharing should not affect employment or production since they are targeted at excessive *net* profits, which arise after labor and all production costs are paid. Neither would such interventions reduce emissions directly. Governments can however use the significant extra state revenue for investments in better forest management, law enforcement, anti-corruption measures, declining CFU proposals with marginal country benefits, exploration surveys in gold mining, et cetera, for which funding often lacks in developing countries. All of these can reduce forest emissions, hence yield REDD+ earnings. To give some perspective on the magnitude of overall revenues in Guyana's alluvial gold sector, the 1.5% state share reflects $20.6M (Table 2), implying that around an average $1.35 billion worth of gold *profit* (not gold value) might have been extracted per year from Guyana's soils during 2001–2012. This equals almost twice the entire 2014 state budget (GoG 2015b). As such, next to cleaning supply chains and moving commodity production out of primary forest areas (e.g. Boucher et al., 2011; Strassburg et al., 2014; UN Climate Summit, 2014), cleaning profit chains may be another option for potentially very large, and homegrown, state funds.

4.4.2. Cleaning profit chains outcompeting REDD+

High returns of cleaning profit chains might convince governments to pursue these instead of REDD+ earnings, which might potentially lead to expansion of forest use. However, much higher state returns from CFUs should make forest expansion less necessary, which is of particular importance for natural resource-dependent economies (boom-bust shocks, including in employment). It would also counter the Paris pledge and other international agreements the country may be a signatory to (e.g., indigenous rights, biodiversity, sustainable development goals, etc.) and in Guyana's case the government's 'Green State Development Strategy' vision which aims 'to ensure a sustainable and fair transition to inclusive green growth and a better quality of life for all Guyanese' (Ministry of the Presidency and UNEP, 2017). Cleaning profit chains fits well in this vision, and could contribute with interest-free homegrown funds instead of development loans.

Forecasted rising carbon prices (Carbon Tracker et al., 2017; CPLC, 2017) would be another factor to consider. A $40–80 carbon price puts a $40,000–80,000 ha^{-1} opportunity cost on deforestation in Guyana. Although the narrative has developed that emission reductions are cheap in tropical forests, it seems less clear why global South countries should accept a much lower than the going world carbon price. As profit maximization is a main pillar of global private sector capitalism, and shown here to take place with tropical forest commodities and with chain links often foreign-owned, then imposing a low $5 carbon price for forest emission reductions in developing countries begets an unpleasant flavour. Ironically however, governments of tropical forest countries might accept a low carbon price, if pressured by influencial groups (to keep forest commodities competitive), or reject REDD+ altogether. Civil society in developing countries, including forest-dependent peoples and their allies would therefore likely benefit from demanding full financial analysis of REDD+ potential at the national level, and exert pressure for a carbon price close to the going world price. At the other end, the global community, at the prospect of a viable tool for simultaneous climate change mitigation *and* social and environmental improvement in the tropics, should not allow such to happen and set a commensurate carbon

price for REDD+ emission reductions across the tropics, if not a higher price for the additional co-benefits.

Lastly, since 'national REDD+' is not yet operational worldwide, and hence carbon credits to HFLD countries such as Guyana (for validating emission reductions in other REDD+ countries (international leakage) and rewarding good past forest stewardship) may realistically be even further off, making the assessment and cleaning of profit chains a domestic option is something developing countries do not have to wait for.

4.4.3. Beyond Guyana and beyond REDD+

While the particular ratios of revenue sharing will be unique to Guyana, the general phenomenon of unequal private-state sharing on natural resources is likely not. One main cause or facilitating factor, poor (interior) law enforcement, including non-transparent accounting, is common in perhaps all developing countries (e.g., Dimant, 2013; Gardner et al., 2018; Jetter & Parmeter, 2018; Lambin et al., 2001). Low risk on high returns, due to lacking, easily bribed or intimidated law enforcement, forms a very strong incentive for illegal or unethical practices, while part of accumulated returns can be directed to economic and political leverage to undermine rural or national plans that would interfere with these rural income streams (e.g. land tenure, biodiversity conservation, rights of rural citizens, national REDD+ and equitable benefit sharing, improved law enforcement, transparency, etc.) (e.g. Bolin et al., 2013; Brockhaus et al., 2014). Assessing and 'equitizing' revenue ratios, or cleaning profit chains, may therefore also aid the performance of these sectors, more so since 'equitizing' moves excessive net revenues from private to the owner's hands, as state funds.

While changing the status quo of vested economic and political interests is difficult and possibly dangerous (Global Witness, 2017), levels of motivation for change by government and/or electorate may be harnessed through an awareness of the magnitude of inequity, forecasted REDD+ income losses of CFUs, and of potential levels of financial return from interventions (in a similar fashion as private business motivation correlates with levels of projected revenue). Such economic arguments may generate more viable motivation than ethical justice arguments alone (Duchelle et al., 2018; Rights and Resources Initiative, 2014; Sunderlin et al., 2018; Tauli-Corpuz et al., 2018) to realize forest governance change in sovereign countries and against vested interests. Assessments are best expressed at national level, as local or global inequity figures are unlikely to generate sufficient national electoral motivation for change in a sovereign country.

Through both REDD+ and cleaning profit chains there appears significant potential for Guyanese society to further climb the ranks of the Human Development Index, while simultaneously benefiting their forests and its inhabitants, and mitigating climate change. Other forest nations may find similar cures. Yet it will require industrialized countries backing up and kick starting the REDD+ result-based payment process, in partial fulfillment of their Paris and Nationally Determined Contribution commitments. In this context it is worth noting that, while reforestation will be needed to reduce global CO_2 levels in the atmosphere, avoiding tropical deforestation (REDD+) is a ∼ 150–300 times more effective activity: while a hectare of reforestation sequesters ∼1 ton carbon per year (Baccini et al 2017; Poorter et al 2016), a hectare of deforestation releases ∼150–300 tonnes of past carbon sequestration, depending on the carbon density of the forest, Section 4.1.1).

5. Conclusions

Ten years after its launch, REDD+ progress seems mired by problems of uncompetitiveness, risk of land grabbing, powerful

business-as-usual interests and deserted by global results-based finance, eventhough the scientific and public call for emission reductions has since only become louder and more urgent. This paper, to our knowledge the first, explores the economic performance of 'national REDD+' versus commercial forest uses, and from the perspective of the owner of the resources, here Guyanese society. The technical approval of Guyana's national REDD+ program (FREL submission) by the United Nations demonstrates that even low-income developing countries can become effective partners in combating climate change.

National REDD+ appears to function differently than 'project REDD+' in several aspects. For instance, it is not subject to structural difficulties such as setting reference levels, national leakage, and permanence, while a major concern of inducing land grabbing appears unsubstantiated, particularly when civil society is adequately engaged. A second major concern, uncompetitiveness, also appears unsubstantiated in Guyana, when viewed from the perspective of the country. National REDD+ would make a substantial annual contribution to Guyana's budget, even at a preliminary low US$5 carbon price, several times larger than the combined budget contributions of the country's major drivers of forest emissions, alluvial gold and diamond mining and selective logging. While this can be largely explained by Guyana's High Forest Low Deforestation character, REDD+'s financial competitiveness held up on a hectare basis, which was unexpected for such high value commodities.

Extreme differences in cumulative net revenue between private commodity chains and the state appeared to be the underlying cause. While acknowledging data imperfections of this exploratory study, these are unlikely to cancel out the observed approximately hundred, respectively, thousand fold differences in net revenue. Further study can bring more detail, but this indicative study strongly suggests Guyanese society has been receiving very small portions of its high-value natural resources, indicating that reasonable state interventions are warranted and worthwhile.

Public awareness of the magnitude of longstanding inequity may aid domestic support for interventions, i.e. forest governance change. This should not affect employment or other sector inputs to the economy as net profits arise after production and labor is paid. They could instead provide substantial, homegrown, finance to invest in further securing rational and lawful use of exhaustible forest-based resources. In addition to mitigating boom-and-bust shocks to the economy and employment, doing so would be in line with the Paris pledge and Guyana's Green State Development Strategy, while returning REDD+ income (linearly increasing with forecasted rising carbon prices), mitigating climate change, aiding rights and livelihoods of forest-dependent citizens and all other co-benefits of preserving tropical forests.

Poor law enforcement, prevailing across the tropics, contributes to the skewedness towards private sector returns, while linked economic and political leverage may undermine national plans that would interfere with such forest-based private income streams (e.g. land tenure, indigenous rights, rural development, forest/biodiversity conservation). Assessments and interventions to 'clean profit chains' may therefore not only aid the state budget and national REDD+ implementation, but also the performance of the above sectors.

Domestic motivation for forest governance change based on national economic insights regarding inequity and potential returns of interventions, may be more viable than social justice arguments alone in sovereign developing countries.

6. Data statement

The research in this article did not generate any data or code. It only used documents in the public domain.

Conflict of interest

The authors have declared that no conflict of interest exist.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.worlddev.2019.02.010.

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