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Could REDD+ mechanisms induce logging companies to reduce forest degradation in Central Africa?

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ABSTRACT

In the Congo Basin where nearly 20 million ha of concessions are exploited according to management plans, improved forest management (IFM) has become a strategy of prime importance when setting up the REDD+ mechanism. For logging companies, REDD+ projects provide the opportunity to compensate a voluntary reduction of the logging intensity by valuing the associated carbon gain. We explored, from the perspective of a logging company, a range of scenarios for reducing logging intensity so as to assess the possibilities for emissions reductions and to evaluate the financial feasibility of such projects. On the basis of Monte Carlo simulations for a typical export-oriented forest concession, we calculated intervals of break-even prices of permanent carbon credits. We show that logging intensity reduction is an attractive option when there is a complete cessation of logging, and for little exploited and low-profit forests. The most feasible IFM projects would be those that require a major reduction of logging intensity. Our work suggests that—instead of improving forest logging techniques—IFM projects based on a voluntary reduction of logging intensity would rather lead the exclusive choice of carbon or timber valuation. Carbon market prices are too low to be an incentive to change logging practices toward more climate-smart forest management, and a change of paradigm to change actors' behaviors would be needed.

Introduction

The impact of climate change on the environment and human societies is a major concern for the international community. Mechanisms are being implemented worldwide to mitigate its effects (IPCC, 2014), especially under the aegis of the United Nations Framework Convention on Climate Change (UNFCCC, 2011). The "Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries" (REDD +) mechanism has been designed to implement result-based positive incentives to encourage change in forest-based economic activities to reduce greenhouse gas (GHG) emissions (Angelsen et al., 2012). The financing options and the architecture of the REDD+ mechanism is still being debated and negotiated (Angelsen et al., 2012). In particular, questions about the articulation between the national level where carbon credits are to be accounted and reported and the subnational level where projects should be implemented are yet to be resolved. This lack of clarity allowed the development of numerous self-declared REDD+ projects, generally oriented to voluntary carbon markets (Chagas et al., 2011; Karsenty et al., 2012). The principles behind REDD+ projects relate to proposing an alternative scenario to the implementation of a reference business-as-usual or baseline scenario. Alternative scenarios must

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lead to a reduction in GHG emissions or an increase of GHG sequestration, compared with the baseline scenario. The reduction of GHG emissions generated by the project is converted into permanent tons of CO_2 and allows the project developer to issue carbon credits. These credits, after verification and certification, can be sold on the voluntary market. The revenue should offset the opportunity and transaction costs of the alternative scenario to ensure the project's viability. There are several voluntary schemes that can certify a REDD+ project (Calmel et al., 2011). For this study, we chose the Verified Carbon Standard (VCS, previously Voluntary Carbon Standard), the main independent carbon standard (Goldstein et al., 2014).

In tropical forest lands, natural regeneration, agroforestry, and reforestation were long considered to provide the lowest cost initiatives to attain diminishing GHG emissions (Brown et al., 2002; Dixon et al., 1991); however, these assessments focused on the marginal costs of storing carbon and discarded their opportunity costs. Improved forest management (IFM) activities were initially not seen as promising options to reduce GHG emissions and generate carbon credits. Several reviews have been published about Central Africa (Durrieu de Madron et al., 2011) or on a wider scale (Putz et al., 2008; Timothy et al., 2014) to appraise the links between different modes of timber exploitation and carbon stocks in tropical forests. However, most of these studies restricted their investigation to the quantitative characterization of the carbon balance. Estimates of the break-even price of carbon credits to convince logging companies to modify their management practices in order to attract REDD+ funds are much rarer, at least for tropical forests. These calculations followed two approaches. On the one hand, the financial analysis of improving actual logging practices is based on generic estimates of the profit and the costs, which are modulated by scenarios, as exemplified by (Ndjondo et al., 2014). On the other hand, the estimates of the break-even price of carbon credits are drawn from a comparison of the marginal costs of conventional logging versus reduced impact logging (RIL), according to different scenarios of timber harvesting and logging (Healey et al., 2000). In both cases, the low price of carbon credits on voluntary or binding markets and the high discount rate in tropical countries hardly convince the logging companies to modify their management practices in order to reduce carbon emissions.

In Central Africa, the implementation of REDD+ is a critical issue: forests cover more than 2 million km^2 (Hansen et al., 2013) stock large amounts of carbon, and face various threats of degradation by human activities (OFAC, 2012). Hence, considerable funding resources amounting to USD 550 million have been disbursed to support REDD+ readiness in the region since 2006 (Maniatis et al., 2013). Central African states are the owners of the forest, but forest management and harvesting is largely conceded to private firms (Bayol et al., 2012). Due to lack of human and financial resources, the states delegated the role of forest manager to the logging companies. Felling cycle durations, minimum cutting diameters, and the list of commercial species are the main tools used to regulate timber harvests in time and space (Karsenty et al., 2008). Among REDD+ activities, IFM activities designate the changes of forest management practices that allow an increase of carbon sequestration and/or a reduction of GHG emissions on forest lands managed for wood products (VCS, 2016). Eligible IFM activities include RIL, logged to protected forest (LtPF), extended rotation age/cutting cycle (ERA), and low-productive to high-productive forest (LtHP).

Managed forests are, in this paper, forests managed under national forest codes that have similar features across all central African Countries. They have management plans, which depend on the length of the felling cycle and on the minimum diameter cutting. Managed forests in Central Africa are considered as a proxy for sustainable forest management goals (SFMs). IFM stands for a set of practices, that is, as RIL or silvicultural practices; these practices are designed for reducing degradation during or after logging operations.

As 20 million ha of forests are now managed in Central Africa out of 44 million ha allocated to logging companies in long-term concessions (Angelsen et al., 2012), IFM has great potential to reduce GHG emissions using REDD+ mechanisms. Thus, IFM has been promoted as a key strategy during the implementation of REDD+ mechanisms in timber concessions (Griscom and Cortez, 2013; Somorin et al., 2012). However, IFM projects remain little known in Central Africa. Even if feasibility studies have been conducted for projects such as the Takamanda-Mone Landscape project, the Ngamikka (Kabobo) project in DRC (WCS, 2011), and the Ngoyla-Mintom project in Cameroon (Acworth, 2012), only three REDD+ projects have been implemented so far: the North Pikounda project in the Congo, (Strebel, 2013); and the MaïNdombé (Freund, 2012) and the Isangi projects (Tuttle, 2014) in the Democratic Republic of the Congo (DRC). Only the first two cover IFM projects, and only from the LtPF category.

However, as explained by (Karsenty et al., 2012), the very idea of LtPF projects to compensate logging companies for reducing their emissions by an increase of their conservation surfaces, raises an additional issue: the areas that are proposed to be turned into conservation areas are often technically and/or economically unexploitable.

Alternative IFM projects, without complete cessation of logging activity, appear to be more preferable options but few scientific studies have been devoted to this subject. (Bellassen and Gitz, 2008) investigated the trade-off between shifting cultivation and forest conservation in Cameroon and found that a break-even price of USD $2.85/tCO_2$ would offset shifting cultivation. (Durrieu de Madron et al., 2011) estimated that carbon emissions could be reduced by up to 10% thanks to the use of IFM in Central African forest concessions. Ndjondo et al. (2014) estimated the opportunity cost of IFM in Gabon and found that a break-even price of USD $4.4–25.9/tCO_2$ would balance conventional logging with IFM.

This article analyzes the feasibility of REDD+ projects implemented using the IFM category of reducing logging intensity, from the perspective of a logging company, and under the actual forest codes and certification standards used to determine carbon credits. Starting from the experiments carried out in the project "Support for the sustainable management of forests in the Congo Basin and the Brazilian Amazon Basin" (FORAFAMA), we characterized a generic concession and a baseline scenario representative of logging practices in Central Africa. The FORAFAMA project involved several REDD+ initiatives in three countries: Brazil (Grondard et al., 2013), Cameroon (TEREA, 2013), and DRC (Hirsh et al., 2013). Some project initiatives in Cameroon and DRC consisted in reducing logging intensity in a forest concession and could be considered as voluntary IFM project initiatives. We have compiled information from these initiatives and other sources to build a conceptual framework. This allowed exploring a range of scenarios for reducing logging intensity and discussing their impact on stakeholders and their economic viability.

This study is the first to consider the Congo Basin from the perspective of quantifying the break-even price of carbon emissions reduction for REDD+ projects from the IFM category. It follows rigorously the requirements of the most common standard of the voluntary market. Previous studies for this region aimed to quantify the cost of implementing IFM, but the examined only two logging companies in Gabon (Ndjondo et al., 2014; Medjibe and Putz, 2012) and their financial analyses were less elaborate than ours. We have assessed all the uncertainties in the financial analysis using the Monte Carlo method. This efficient method, rarely used for such financial analysis (Telfer and Sharma, 2014), allows us to obtain confidence intervals of the break-even prices of carbon emissions reduction.

The next section presents the logging model, the baseline scenarios, the REDD+ scenarios, and the parameters used in the simulations. Results section presents the simulation approaches and the computation of indicators. Discussion section presents the achievements of the simulations of the scenarios and the comparisons of baseline scenarios with each of the REDD+ scenarios. The Discussion section presents an analysis of the REDD+ scenarios and their impacts on stakeholders and of their economic viabilities.

Material and Methods

Case study: logging concessions in Central Africa

Management plans of logging concessions are supposed to ensure the sustainable exploitation of timber after the first cutting cycle, which removes the "forestry premium" (Putz et al., 2012). Based on national forest codes that have similar features across all Central African countries, management plans depend on the length of the felling cycle and on minimum diameter cutting limits. For example, if the logging cycle is 25 years, the productive series of the concession is divided into 25 units of similar annual allowable cut surface. Timber harvesting occurs each year for a predetermined annual allowable cut surface and after 25 years, the logging company can go back to the first annual allowable cut surface.

Logging companies need a dense network of forest roads and trails, and this is one of the main expenditure items of timber production (Carret and Clement, 1993) as quoted in (Wilkie et al., 2000). The roads network is composed of three categories of roads: main roads, secondary roads, and skid trails (Hirsh et al., 2013; CTFT, 1989) (see supplementary material for details).

The species generally harvested and exported by large concessions in Central Africa are ayous, azobe, beli, bibolo/dobétoui, bilinga, iroko, khaya (mahogany), moabi, movingui, niové, okan, okoumé, padouk, sapele, sipo, and tali (ITTO, 2014). We estimated the sales revenue of a concession by taking into account the selling price of these species on Asian export markets and the volume of their production assuming, that they comprised only logs and sawnwood.

Baseline and REDD+ scenarios

The IFM project area is designated for wood product management by a national or local regulatory body (e.g., as logging concessions or plantations) (VCS, 2016). For this study, we assumed that IFM was being carried out by each logging company on a concession totaling 150,000 ha of productive series for 25 years. These are common values for felling cycles and concession areas in Central Africa (OFAC, 2012; TEREA, 2013; Hirsh et al., 2013; CTFT, 1989).

We defined the baseline and REDD+ scenarios as conventional logging operations on the same annual allowable cut surfaces; here, 6,000 ha for each of the 25 years of the project. The baseline and REDD+ scenarios differed only by the logging intensity that was applied. The logging intensity was lower for the REDD+ scenario than for the baseline scenario in order to reduce the level of CO_2 emissions. In practical terms, reducing the logging intensity can be obtained through several activities of the IFM category of REDD+ projects: through RIL activities by improving the selection of logs or through ERA activities by extending the minimum cutting diameter (MCD). The extreme case of the logging intensity being equal to zero corresponds to LtPF activities.

Homogeneous values were reported for conventional logging intensities in Central Africa (range 1–2 or 2.5 trees ha^{-1} (Brown et al., 2005; Dupuy, 1998; Fargeot et al., 2004). For the logging intensity of the baseline scenario, we considered all values between 1 and 2.5 trees·ha^{-1}, with a step of 0.1 trees·ha^{-1}. For the logging intensity of the associated REDD+ scenario, we considered all values between 0 and the logging intensity of the baseline scenario, with a step of 0.1 trees·ha^{-1}.

The cases of RIL/ERA activities (logging intensity > 0) and LtPF activities (logging intensity = 0) of the REDD+ scenarios were managed separately because we considered two subcases for the LtPF activities: (i) the concession has never been logged before and the main roads were built for the baseline scenarios; and (ii) the concession has been logged before and the main roads had already been built.

Modeling and simulating logging operations to assess REDD+ scenarios

We built a model of a forest concession (see Fig. 1) that estimates the CO_2 balance and the profit of the concession for each year of a baseline or REDD+ scenario, starting from two variables: the annual allowable cut surface and the logging intensity. Carbon changes were estimated using the gain–loss method depicted in Box 2 Box 2.3.9 (p.74) of (GOFC-GOLD, 2012). CO_2 emissions and sequestration were computed as the product of activity data (here, forest areas that are degraded or that recover from former degradation) times emission factors. Approach 1 (sensu IPCC 2006) was used for activity data ((GOFC-GOLD, 2012)§1.2.3.1) and Tier 2 was used for emission factors ((GOFC-GOLD, 2012)§1.2.3.2).

The model integrates the variability of almost all components. Its state variables (number of felled trees, gap and landing areas, and so on) are randomly drawn conditionally on the values of the model parameters. Simulating a scenario consisted in the following sequential steps for each year of the project:

1. Sampling the number of felled trees according to a Poisson distribution with the parameter being equal to the product of the annual allowable cut surface and the logging intensity.
2. Sampling the gaps and landing surfaces depending on the number of felled trees.
3. Sampling the lengths and surfaces of the main roads, secondary roads, and skid trails, depending on the annual allowable cut surface and logging intensity.
4. Computing the degraded surfaces, depending on steps 2 and 3.
5. Sampling the CO_2 emissions, depending on the degraded surfaces.
6. Computing the forest road costs, depending on their lengths.
7. Sampling the timber production and logging revenue, depending on the number of felled trees.
8. Computing the production costs, depending on timber production and road costs.
9. Sampling CO_2 sequestration, depending on the degraded surfaces and on the timber production of the previous years.
10. Sampling logging company profit percentages according to a uniform distribution over a predefined range.
11. Computing the CO_2 balance and the profit.

For most sampling steps, the values were randomly generated according to a normal distribution; the exceptions were steps 1 and 10, where Poisson and uniform distributions were used, respectively.

Most of the model parameters (Table 1, Table 2) differ between logging companies and even within annual harvests. To integrate this variability into the simulations, we introduced a second level of randomness related to these parameters using a Monte Carlo scheme. The Monte Carlo approach consists in proceeding to a large number of simulations to handle all the randomness. We performed 10,000 simulations for each scenario, with parameter values sampled according to their probability distribution for each simulation. Most often, we used a normal distribution with parameters (mean

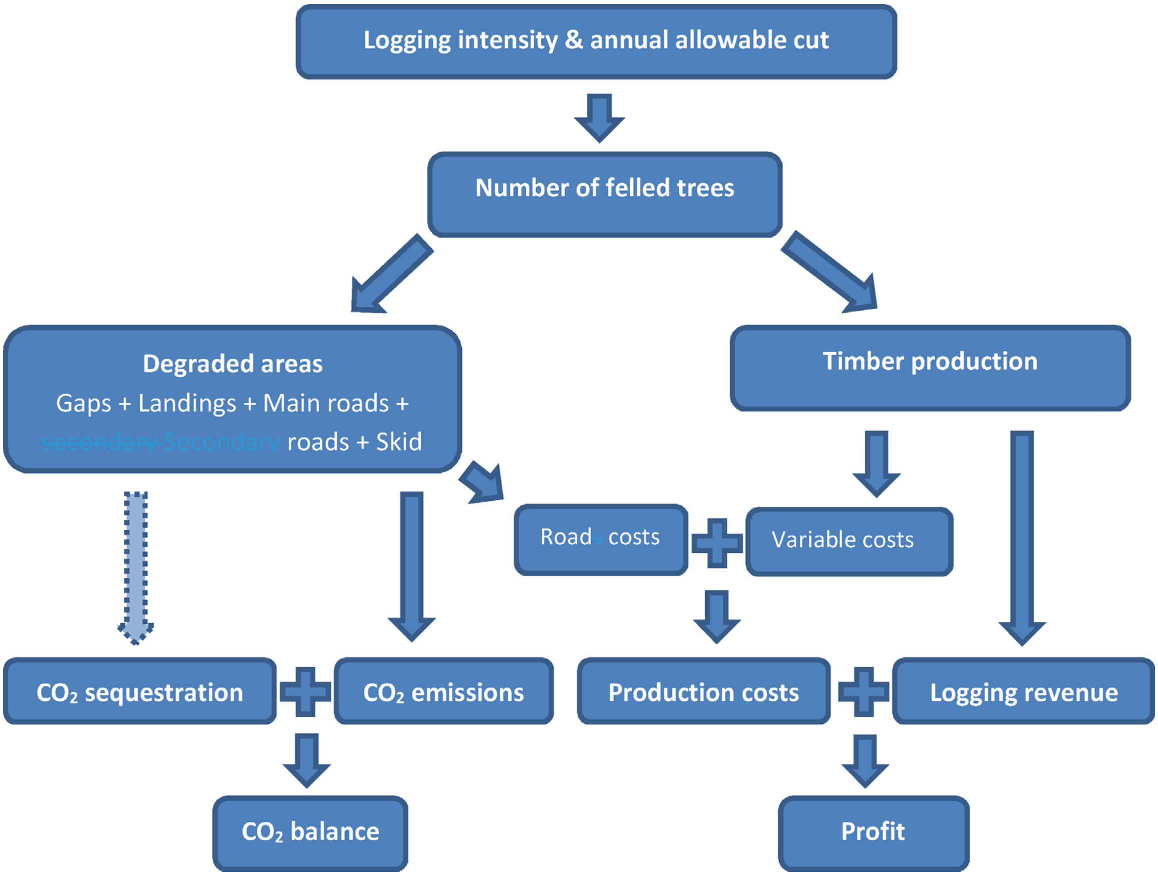

Fig. 1. Scheme of the model used to simulate the scenarios.

Table 1
Concession model parameter values.

Parameters	Values (mean ± SD)	References
Forest carbon stock ($tCO_2e\ ha^{-1}$)	728.96 ± 129.81	(Djuikouo et al., 2010; Medjibe et al., 2011; Gourlet-Fleury et al., 2013; Lewis et al., 2013)
Forest recovery rate ($tCO_2e\ ha^{-1}\ year^{-1}$)	7.8 ± 3.17	(Durrieu de Madron et al., 2011; Gourlet-Fleury et al., 2013; Djomo et al., 2011; Preece et al., 2012)
Ratio of forest biomass for trees with dbh <20 cm (%)	10	(Gourlet-Fleury et al., 2011)
Wood specific gravity (WSG) ($g\ cm^{-3}$)	0.6	(Henry et al., 2010)
Conversion of AGB into carbon	0.47	(Eggleston et al., 2006)
Conversion of carbon into CO_2e	44/12	(Eggleston et al., 2006)
Main road width (m)	42.15 ± 4.03	(Hirsh et al., 2013; CTFT, 1989)
Secondary road width (m)	27.4 ± 3.68	(CTFT, 1989)
Main and secondary roads length ($m\ ha^{-1}$)	11.18 ± 1.9	(TEREA, 2013; Hirsh et al., 2013; CTFT, 1989)
Secondary/main roads proportion	0.68 ± 0.14	(Hirsh et al., 2013), supplementary material
Skid trail width (m)	4.5	(CTFT, 1989; Medjibe et al., 2011; Durrieu de Madron et al., 2000)
Skid trail length (m)	$19.83 \times \log(1 + 42.62\ (\text{Logging intensity})^{2.96}) \pm 10.17$	Supplementary material
Gap surface (m^2)	521.1 ± 168.7	(Brown et al., 2005; Dupuy, 1998; Medjibe et al., 2011)
Landing surface (m^2/felled tree)	28 ± 5.31	(Durrieu de Madron et al., 2000; Ndassa, 2010; Pallisco, 2012)

Table 2
Logging revenue and cost parameters. Computation details are provided in the supplementary material.

Parameters	Values (mean ± SD)	References
Commercial volume of logs ($m^3 \cdot tree^{-1}$)	8.5 ± 3.1	(CTFT, 1989)
Sawnwood volume/Log volume(processing rate)	30–35%	(Eba'a Atyi, 1998)
Log price free on board (EUREUR m^{-3})	282.08 ± 39.04	(OFAC, 2012; ITTO, 2014)
Sawnwood price (EUREUR m^{-3})	502.66 ± 74.7	(OFAC, 2012; ITTO, 2014)
Main road cost (EUREUR m^{-1})	7.3	(FAO, 1998)
Secondary road cost (EUREUR m^{-1})	4.4	(FAO, 1998)
Skid trail cost (EUREUR m^{-1})	1.4	(FAO, 1998)

and standard deviation) taken from the literature and from the FORAFAMA project (see supplementary material).

However, we avoided overestimating the uncertainties by performing conjointly, for each comparison, the simulations of the baseline scenario and of the REDD+ scenarios. More specifically, the random quantities that did not depend on logging intensity—for example, the main and secondary road areas—were equal for the baseline scenario and the REDD+ scenarios, but varied across simulations.

Components of the model

A more detailed technical description is available in the supplementary material.

Degradation induced by conventional logging operations

Logging operations trigger deforestation and forest degradation (Table 1). (i) Each felled tree created a logging gap, and we assumed that all the biomass was lost in gap areas. (ii) The logs were stored in landings before being transported out of the concession; we assumed that the whole biomass was cleared in landing areas. (iii) The forest road network had been built to get access to the wood resources; we assumed that the whole biomass was lost in the main and secondary road areas and that the biomass of trees < 20 cm in diameter at breast height (dbh) was lost in the skid trail areas.

CO_2 emissions

CO_2 emissions were caused by: (i) deforestation in gaps, landings, and along main and secondary forest roads; (ii) degradation along skid trails; and (iii) harvested wood product decomposition.

Following VCS (2016), we modeled dead wood pool decomposition using a 10-year linear decay function. We quantified the total CO_2 emissions over 10 years due to deforestation by multiplying the cleared areas with a theoretical carbon stock for undisturbed forests in the Congo Basin (Table 1). We quantified the total CO_2 emissions over 10 years due to degradation by multiplying the surface of the degraded areas by a theoretical carbon stock for undisturbed forests in the Congo Basin and by a proportion associated to the degradation (Table 1). We quantified the annual CO_2 emissions due to deforestation and degradation, applying the 10-year linear decay function to the total CO_2 emissions over 10 years.

Following Eggleston et al. (2006), we modeled the decomposition of harvested wood products (*i.e.*, sawmill products in our study) with an exponential decay function with a half-life of 20 years (Dhôte and Impact et al., 2016). We quantified the annual CO_2 emissions due to decomposition of harvested wood products by applying the exponential decay function to the volume in tCO_2e of sawmill products.

CO_2 sequestration

Net CO_2 sequestration had occurred in the degraded and deforested areas during the previous years. We quantified the net CO_2 sequestration by multiplying the total surface of the degraded and deforested areas of all previous years with a representative net sequestration rate for disturbed forests in the Congo Basin (Table 1). We assumed in the simulations that the sequestration of CO_2 started the year after the gaps, skid trails, and secondary road areas had been logged until the end of the project; and that the sequestration of CO_2 started five years (Hirsh et al., 2013) after logging in the landings and main road areas until the end of the project. Net CO_2 sequestration in landings and along main roads was delayed to take into account soil compaction, which slows down the recovery of vegetation.

According to (VCS, 2016), IFM methodologies applicable to activities that reduce harvested timber will account for the CO_2 emissions associated with changes in the wood products pool to avoid overestimating project CO_2 sequestration. The quantity of CO_2 sequestered in harvested wood products was quantified using the conversion rate from logs to sawnwood (Table 2).

Logging revenue

The logging revenue came from the selling of timber. We computed the volume of timber as logs and as sawnwood, taking into account the logging intensity and technical parameters representative of the Congo Basin concessions (Table 2). We assumed that timber production was exported, since most domestic markets are supplied with artisanal sawnwood (Cerutti and Lescuyer, 2011). We computed the selling price while taking into account the species harvested and the export prices from the Congo Basin (Table 2).

Profit

The profit is the difference between the logging revenue and the production costs. For the REDD+ scenarios, the profit was computed using the basic formula:

$$Profit_{REDD+} = LoggingRevenue_{REDD+} - \mathrm{ProductionCosts}_{\mathrm{REDD+}} \quad (1)$$

For the baseline scenario, we considered *x*, the profit rate of the logging company, using:

$$Profit_{baseline} = x\% \times LoggingRevenue_{baseline} \quad (2)$$

We used three ranges of values for *x* to analyze the sensitivity of this parameter on the viability of the REDD+ projects: high 13–17, medium 8–12], and low 3–7.

Production costs

Two types of production costs were considered: the road network costs and the variable costs (see supplementary material for details).

Assessing the economic viability of a REDD+ scenario for the logging company

Transaction costs of a REDD+ project

REDD+ projects should reduce GHG emissions. The GHG emissions reduction of the project has to be quantified in carbon units (CU; 1 Mg eCO_2) and validated by VCS before verified carbon units (VCUs) are issued. The VCS procedure to issue and sell VCUs is based on several steps (Calmel et al., 2011; Brimont, 2014; Carter Ingram et al., 2009; Chenost et al., 2010):

1. Pre-feasibility study: the project concept and its limits are presented via a project idea note (PIN).
2. Feasibility study: baseline and alternative scenarios are developed, the monitoring plan and review of methodologies are presented in a project design document (PDD), and revisions or development of a new methodology are adapted to the scenarios.
3. Validation: validation of the project is done by an independent entity.
4. Operational: emission reductions are monitored and data are presented in a monitoring report.
5. Monitoring: every 5 years (VCS, 2008a), verification of CO_2 emission reductions is carried out by an independent entity accredited by VCS.
6. Delivery: registration of the VCUs is generated in the VCS register.
7. Selling: brokerage fees are determined.

Following White and Minang (2011), we designated by transaction costs, the costs of the above steps. The costs of the first three steps are supported only once, at the beginning of the project (Table 3). The costs of operational activities are supported each

Table 3
Main steps and costs of producing VCUs.

Steps	Frequency	Cost bounds
Pre-feasibility PIN (kEUR)	once	10 68.27
Feasibility PDD (kEUR)	once	13.65300
Contractualization (kEUR)	once	5-136.55
Methodology (kEUR)	once	50-200
Validation (kEUR)	once	20-50
Monitoring (EUR ha^{-1})	5 years	0.38-6.45
Verification (kEUR)	5 years	20-50
Registration (EUREUR VCU^{-1})	Per VCU generated	0.034-0.2
Brokerage (%)	For each sale	2-15

Sources (Calmel et al., 2011; Brimont, 2014; Carter Ingram et al., 2009; Chenost et al., 2010).

year in order to monitor the annual allowable cut that has been exploited. The costs of verification, delivery, and sale are all supported every 5 years. For the simulation, we sampled each cost value according to a uniform distribution on the intervals given in Table 3.

Number of verified carbon units (VCUs) issued and sold.
According to (VCS, 2016), the maximum number of VCUs issued by the project shall not exceed a threshold equal to the long-term average GHG benefit. The long-term average GHG benefit (LA) is the annual average of the project CU over the duration of the project (Fig. 2). Once this threshold is reached, no more VCUs can be issued from the project.

As soon as the CU is validated, the VCU can be sold on the voluntary market. However, it is recommended by VCS to provision a part of the VCUs to cover any failure of the project before the end (VCS, 2008b). We used a buffer of 22% (Ndjondo et al., 2014) in such a way that every 5 years, 22% of the VCUs generated were buffered and 78% were sold. Verification and delivery fees were counted for all the VCUs issued, while brokerage fees were counted for the VCUs sold.

Computation of the VCU break-even price

For each joint simulation of the baseline and REDD+ scenarios, we computed the annual differences between the CO_2 balances and the profits to obtain: 1) the annual levels of CO_2 reduction due to the REDD+ scenario; and 2) the annual opportunity cost associated:

$$OpportunityCosts = Profit_{baseline} - \mathrm{Profit}_{\mathrm{REDD+}} \tag{3}$$

Following the VCS recommendations (VCS, 2008a), we determined a timetable for the production and sale of the VCUs. Then we computed the costs of transaction of the REDD+ projects and the quantities of VCUs sold each year.

We used net present values (NPVs) and thus actualized all the previous costs with a 12% discount rate as used in (Ndjondo et al., 2014) and as recommended by (Halsnæs et al., 2007; Harrison, 2012). We divided the NPV of the opportunity costs by the net present quantity of VCUs sold to obtain the gross break-even price of the VCUs. We divided the sum of the NPVs of the opportunity and the transaction costs of the REDD+ project by the net present quantity of VCUs sold to obtain the net break-even price of the VCUs, which is the minimum selling price ensuring the economic viability of the REDD+ project.

$$\begin{aligned} &Gross\ VCU\ break\text{-}even\ price = Opportunity\ Costs_{NPV} \\ &\quad /\mathrm{Number\ VCUs\ sold}_{\mathrm{NPV}} \end{aligned} \tag{4}$$

$$\begin{aligned} &Net\ VCU\ break\text{-}even\ price = (Opportunity\ Costs_{NPV} \\ &\quad + Project\ transaction\ Costs_{NPV})/\mathrm{Number\ VCUs\ sold}_{\mathrm{NPV}} \end{aligned} \tag{5}$$

For each joint simulation of the baseline and REDD+ scenarios, we computed the VCU gross and net break-even prices. We computed the mean and the standard deviation for these prices obtained from 10,000 simulations.

Results

IFM-RIL/ERA activities

Over all simulated REDD+ scenarios, the mean VCU net break-even price was between EUR 5.31–10.91 (standard deviation between EUR 0.49–0.6), EUR 12.89–18.4 (standard deviation between EUR 0.59–0.78), and EUR 20.39–25.84 (standard deviation between EU 0.75–0.98) when respectively the profit percentage of the logging company was 3–7%, 8–12%, and 13–17% (see Table 4, Figs. 3 and 4, and supplementary material).

The lower the profit percentage of the logging company was found to be, the lower the VCU break-even price (Table 4). The logging intensities of the baseline scenario had little effect on the VCU break-even price; rather, they depended on the logging intensity of the REDD+ scenario (Table 4, Fig. 3). The lower the logging intensity of the REDD+ scenario, the lower the VCU gross and net break-even prices seemed to be. The standard deviations of the estimates of the VCU gross and net break-even prices had low variability (Fig. 4). The standard deviations of the estimates of the VCU gross and net break-even prices increased when the difference between the logging intensities of the baseline and of the REDD+ scenarios decreased (Fig. 4). The logging intensities of the baseline and of the REDD+ scenarios also affected the REDD+ project transaction costs (represented by the difference of the two subplots of Fig. 3). Roughly, the lower the amount of VCU generated, the greater was the share of transaction costs in overall costs (transaction plus opportunity costs).

IFM-LtPF activities

Over all simulated REDD+ scenarios, in the case where main roads have to be built for the baseline scenarios, the mean VCU net break-even price was EUR 4.63–6.6 (standard deviation EUR 0.36–0.43), EUR 8.08–12.68 (standard deviation between EUR 0.45–0.55), EUR 11.55–18.75 (standard deviation EUR 0.56–0.72) when respectively the profit percentage of the logging company was 3–7%, 8–12%, and 13–17% (see Table 5, Figs. 5 and 6 and supplementary material). Over all simulated REDD+ scenarios, in the case where main roads do not need to be built for the baseline scenarios, the mean VCU net break-even price was EUR 6.06–7.18 (standard deviation EUR 0.54–0.95), EUR 10.65– 13.82 (standard deviation EUR 0.81–1.58), and EUR 15–20.48 (standard deviation EUR 1.1–2.24) when respectively the profit percentage of the logging company was 3–7%, 8–12%, and 13–17% (see Table 5, Figs. 5 and 6 and supplementary material).

The lower the profit percentage of the logging company, the lower were the VCU break-even prices (Table 5). VCU break-even prices were lower for the baseline scenarios assuming that main roads had to be built. In addition, the VCU break-even prices were more important for higher logging intensity of the baseline scenario. The standard deviations of the estimates of the VCU gross and net break-even prices depended only slightly on the logging company profit (Figs. 5 and 6). The logging intensities of the baseline scenarios also affected the REDD+ project transaction costs (Figs. 5 and 6). Similarly to the IFM-RIL/ERA activities, the lower the amount of VCU generated, the more expensive were the transaction costs.

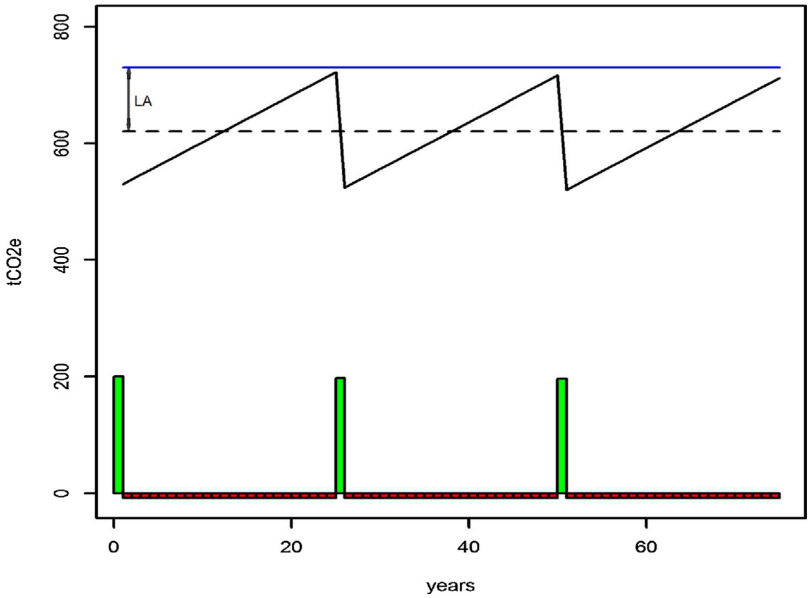

Fig. 2. Illustration of a REDD+ scenario with LtPF activities on flux and stock of CO_2 in 1 ha of forest. Forest carbon stock evolution under the baseline scenario i.e. conventional logging (black line); average forest carbon stock under the baseline scenario (dashed black line); average forest carbon stock under the REDD+ scenario, i.e., no logging (blue line); annual CO_2 sequestration/emissions for the REDD+ scenario (green/red bars). The long-term average GHG benefit is given by: LA = average forest carbon stock under the REDD+ scenario − average forest carbon stock under the baseline scenario. Hence, the first year of the project, only LA VCUs can be issued, even though the amount of CUs is greater than LA.

Table 4

Estimates of the net VCU break-even prices (mean ± SD EUREUR) according to the logging intensities of the REDD+ and baseline scenarios (rows and columns respectively) assuming that logging company profit was 8-12%. These estimates were computed from 10,000 Monte Carlo simulations of the RIL/ERA REDD+ scenarios.

REDD + logging intensity (trees ha^{-1})					
2					18.4 ± 0.78
1.5				18.4 ± 0.78	17.9 ± 0.7
1			17.54 ± 0.76	17.36 ± 0.68	17.13 ± 0.66
0.5		14.92 ± 0.69	15.59 ± 0.64	15.76 ± 0.63	15.79 ± 0.62
0.1	12.89 ± 0.65	14.04 ± 0.62	14.47 ± 0.6	14.69 ± 0.6	14.78 ± 0.59
Baseline logging intensity (trees ha^{-1})	0.5	1	1.5	2	2.5

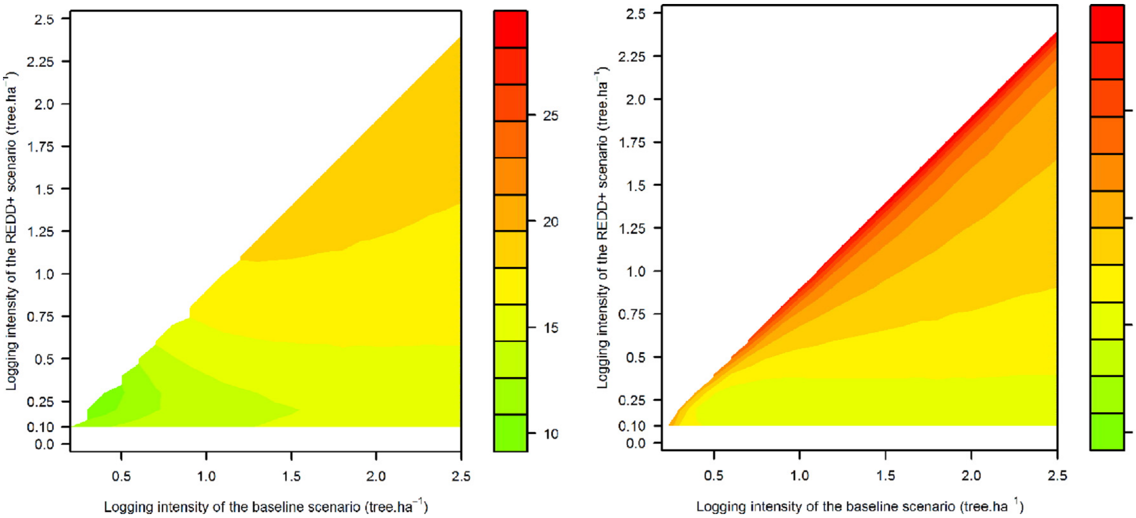

Fig. 3. Mean estimates of the VCU gross and net break-even prices (EUREUR) (left and right, respectively) according to the logging intensities of the baseline and REDD+ scenarios assuming that logging company profit was 8–12%. These estimates were computed from 10,000 Monte Carlo simulations of the RIL/ERA REDD+ scenarios.

Discussion

Economic viability of the REDD+ scenarios for logging companies

Today, the price of tCO_2e on the voluntary market is around EUR 6 (EUR 6.7, EEX Primary Auction Phase 3 EU, March 19, 2015; ECX CARBON SG 0113, last trading EUR 5.98, December 20, 2012). For IFM-RIL/ERA activities: with medium or high logging company profit (higher than 7%), the net break-even price of VCUs was higher than the market price; with low logging company profit (3–7%), the net break-even price of VCUs was lower than the market price if log-

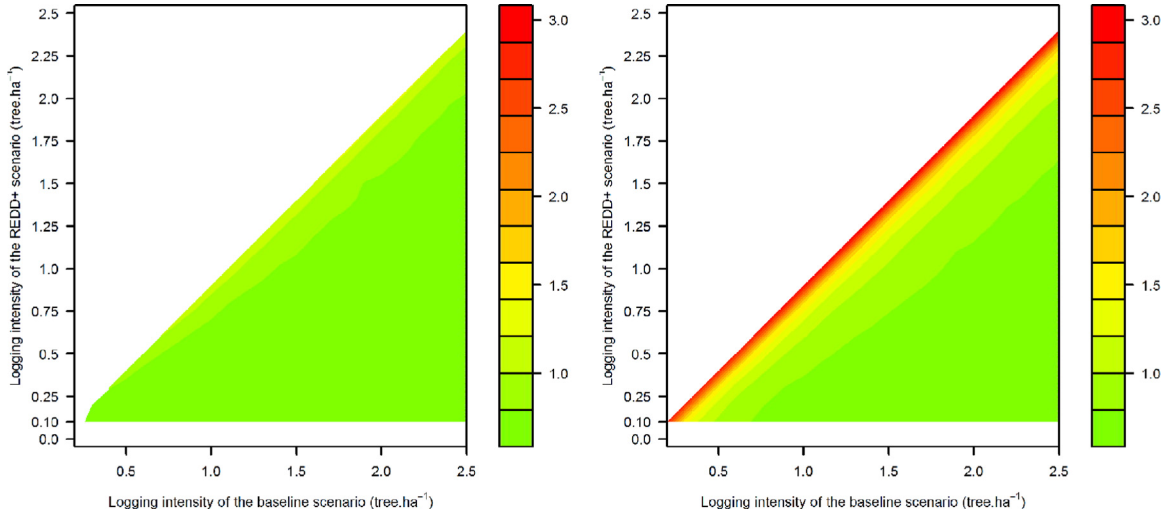

Fig. 4. Standard deviation estimates of the VCU gross and net break-even prices (EUR) (left and right, respectively) according to the logging intensities of the baseline and REDD+ scenarios assuming that logging company profit was 8–12%. These estimates were computed from 10,000 Monte Carlo simulations of the RIL/ERA REDD+ scenarios.

Table 5

Estimates of the net VCU break-even prices (mean ± SD) according to the logging intensities of the baseline scenarios and as to whether main roads have to be built or not for the baseline scenarios, assuming that logging company profit was in the region 8–12 percent. These estimates were computed from 10,000 Monte Carlo simulations of the IFM-LtPF REDD+ scenarios.

Profit of logging companies of between 8% and 12%				
Main roads have to be built for the baseline scenarios	yes		no	
Baseline logging intensity (trees ha^{-1})	Gross VCU break-even price (EUR)	Net VCU break-even price (EUR)	Gross VCU break-even price (EUR)	Net VCU break-even price (EUR)
0.5	6.93 ± 0.35	8.08 ± 0.45	9.17 ± 1.36	10.65 ± 1.58
1	9.48 ± 0.45	10.33 ± 0.5	11.35 ± 1.1	12.33 ± 1.19
1.5	10.81 ± 0.49	11.49 ± 0.53	12.36 ± 0.94	13.11 ± 0.99
2	11.62 ± 0.53	12.2 ± 0.55	12.91 ± 0.85	13.54 ± 0.89
2.5	12.17 ± 0.53	12.68 ± 0.55	13.27 ± 0.78	13.82 ± 0.81

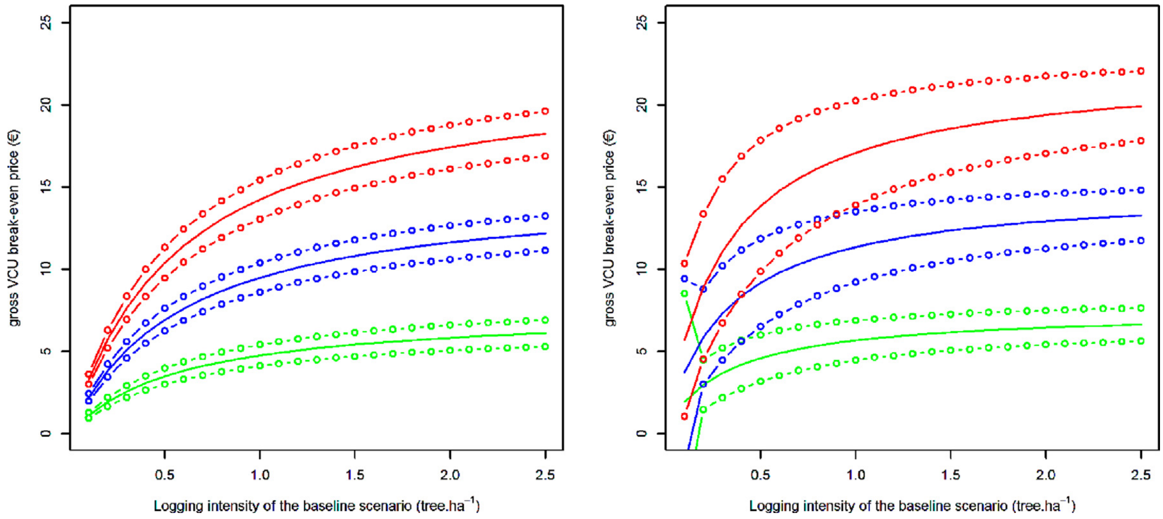

Fig. 5. Gross VCU break-even price for the REDD+ scenario for IFM-LtPF according to the logging intensity of the baseline scenario mean (–) and 95% confidence interval (-o-). A logging company profit of 13–17% is in red, 8–12% in blue, and 3–7% in green. Main roads have to be built for the baseline scenarios (left); and main roads do not have to be built for the baseline scenarios (right).

ging intensity of the REDD+ scenario was lower than 0.5 trees·ha^{-1}. For IFM-LtPF activities: with a medium to high logging company profit, the net break-even price of VCUs was higher than the market price; with a low logging company profit, the net break-even price of VCUs was close to the market price and even lower if the concession had never been logged.

The logging company profit rate strongly affected the break-even prices, which emphasizes the trade-off between logging production and VCUs.

(Hofstad and Araya, 2015) reported a net break-even price of USD 10–40 for wood harvest REDD+ scenarios in Tanzania woodlands. These values are consistent with ours, considering that the

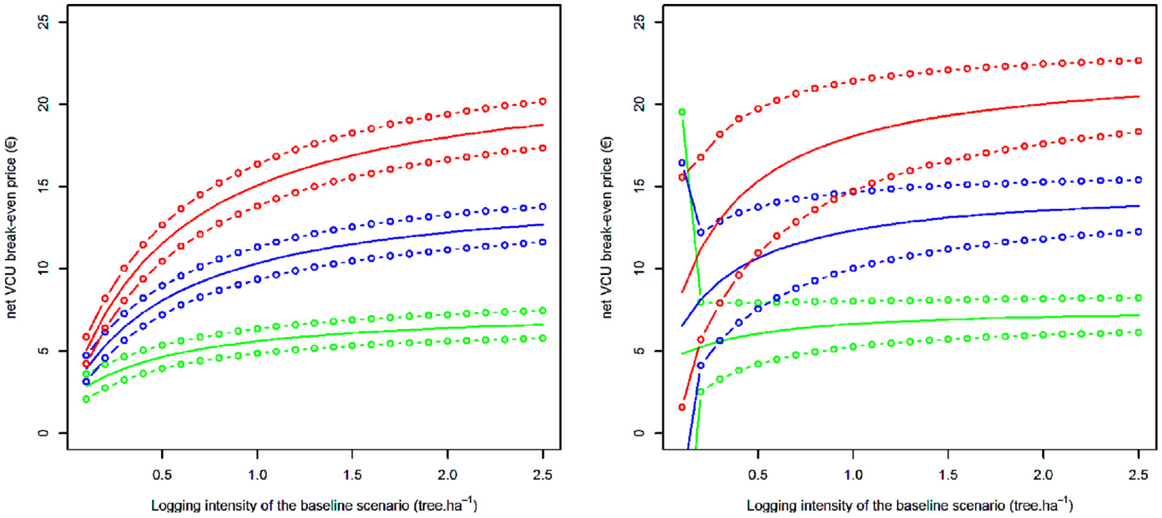

Fig. 6. Net VCU break-even price for the REDD+ scenario for IFM-LtPF according to the logging intensity of the baseline scenario mean (–) and 95% confidence interval (-o-). A logging company profit of 13–17% is in red, 8–12% in blue, and 3–7% in green. Main roads have to be built for the baseline scenarios (left); and main roads do not have to be built for the baseline scenarios (right).

native carbon stock is lower in woodland than in Central African forest, and that the impacts of logging in Central Africa and of harvesting in woodlands are very different. Moreover, we found for IFM-RIL/ERA activities with low logging company profit, taking into account all the REDD+ scenarios, a net VCU break-even price interval consistent with the interval EUR 5–15 reported by (Ndjondo et al., 2014) for REDD+ scenarios in a Gabonese concession. This consistency enforces our results because a different methodology for accounting VCUs was used by (Ndjondo et al., 2014). First, the forest road network and the degraded surfaces were not explicitly managed by (Ndjondo et al., 2014), where a constant rate of mortality of 10% was applied in the low-diameter classes after each logging. Second, a matrix model was used by (Ndjondo et al., 2014) to quantify the CO_2 sequestration after logging, using the administrative parameter values for growth and mortality. The ecological representativeness of these administrative values is questionable.

Differences between REDD+ scenarios

The LtPF projects appeared more feasible than the RIL/ERA projects due to the cost reduction linked to the fact that there was no need to build a forest road network. Among the RIL/ERA projects, the higher the logging intensity reduction, the lower were the VCU break-even prices and their uncertainties. The VCU break-even prices were even lower if the logging intensity of the baseline scenario was low (less than 1 tree·ha^{-1}). The project transaction costs accounted for a large part of the net VCU break-even price for REDD+ scenarios that brought about low CO_2 reductions.

Importance of opportunity cost knowledge for climate negotiations

A better knowledge of the opportunity costs of a ton of CO_2 not emitted in the forest sector will be paramount for countries of Central Africa in future climate negotiations in the context of Nationally Determined Contributions (NDCs). In December 2015 at the Conference of the Parties (COP) 21 in Paris, 188 countries presented their Intended Nationally Determined Contributions (INDCs). These INDCs became commitments in line with the COP21-Paris decision as countries ratified the Paris Agreement. These countries decided to act as soon as possible to maintain “the increase in the global average temperature to well below 2 °C above pre-industrial levels” (Article 2 COP21 decision COP21, 2015). The decision taken in Paris is a call for additional efforts, which countries should translate into their national policies and state in their NDCs. These planned efforts should be credible and ambitious. National commitments are based on scenarios such as those of REDD+; however, these scenarios could cover all sectors. Every 5 years, the assumptions and data underlying these NDC scenarios will be revised to make them more credible and accurate.

The NDCs of Central African countries indicate important reduction efforts in the agriculture, forestry and other land use (AFOLU) sector financed through international funds. NDCs represent a paradigm shift with REDD+. A shift was not intended for reducing degradation and avoiding deforestation or for how reductions are measured, but for offering the means to achieve this result. With NDCs, behavior changes are expected initially from national policies and international cooperation instead of relying on a global carbon market still under construction. This raises new questions from the perspective of state and national policies.

Knowing the opportunity cost of a ton of CO_2 not emitted is a contribution, which will help countries to allocate their reduction efforts across sectors and to minimize potential negative impacts of climate policies on their national economy.

Wood prices

We wondered whether prices could increase if we reduced the wood supply as in the LtPF scenario. We reasoned that, in this context, equilibrium theory cannot apply for a market of tropical wood from natural forest, for two main reasons. First, many substitutes for tropical forest wood exist, such as plantation wood for plywood and plastic for window frames. Second, because we are studying only a small fraction of the tropical wood producers that adopt IFM to benefit from REDD+ credits, they will not have the macro impacts necessary to influence global wood prices. Thus, reducing the timber supply would unlikely drive prices up.

Study limits

We assumed that the forest was in a steady state without CO_2 sequestration when unlogged. The parameter ranges characterizing the concessions used for simulations encompass the values reported for Central Africa. The results of this study are not representative of IFM projects for concessions whose characteristics are outside these ranges. In particular, as we pointed out previously, the mean gap surface, which affects the VCU break-even price, depends in turn on the canopy structure of the forest in the concession.

The study raised a drawback with regard to the implementation of the IFM-REDD+ project. Contrary to the monitoring, reporting and verification (MRV) requirement of transparency, accuracy, and consistency, the number of VCUs is dependent on the methodology used. More specifically, the data available in the literature to estimate biomass recovery rate after logging are very poor. We cannot ensure that the range used for this rate is representative of the heterogeneity of the Congo Basin forests. This is due to the lack of knowledge on forest dynamics in Central Africa. The settlement of a large network of permanent sample plots over the Congo Basin could improve this knowledge.

An assumption of our study was that the sawing activity of the logging companies implementing the REDD+ project was not dependent on the reduction of the volume of logs due to the REDD+ project. This assumption allowed us to consider that the permanent and variable costs remained unchanged.

We assumed that the length of the forest main and secondary roads was the same for any logging intensity. This assumption may not be realistic for very low logging intensities.

We assumed a static economic framework, i.e., stability over the project duration for the selection of species logged, wood prices, and fuel costs, whereas the species logged and their prices depend on the market demands. Changes in economic parameters cause changes in logging company profit rates. As we compared several logging companies' profit rates, the results of this study remain informative for moderate variation of the economic parameters.

We did not include the depreciation of equipment in the calculation of opportunity costs because this information was not available. This could lead to an overvaluation of the selling price of the VCUs.

The CO_2 emissions due to fuel consumption by vehicles and machinery during logging were not taken into account. It implies an underestimation of the amount of VCUs generated. The break-even price of the VCUs was then overvalued. However, as the CO_2 emissions due to fuels represent about 10 kg m^{-3} of logs harvested (Guitet, 2011), the VCU break-even price range would not change significantly.

We have explicitly taken into account the variability of the technological and biophysical conditions. Although the socioeconomic conditions of logging companies are very homogeneous in Central Africa, for historical reasons (Karsenty, 2007), there may be local specificities challenging prices for VCUs obtained in this study. These local specificities were only addressed by considering several profit rate percentages.

Conclusion

The REDD+ scenarios that reduce the intensity of timber exploitation bring a decrease in the CO_2 emissions of the concession. The opportunity costs and the REDD+ project transaction costs were covered by the sale of the VCUs at the current prices on the voluntary markets for logging companies with low profit. The higher the logging intensity reduction, the lower was the net VCU break-even price, with the lowest price being obtained for forest conservation.

In the REDD+ paradigm, the carbon credit market mechanism is central; it should generate a powerful incentive to change actors' behaviors, which generally adversely impact tropical forests. The aggregation of these behavioral changes would reduce GHG emissions at the country scale by reducing forest deforestation and degradation. In line with this idea, this article looks at carbon market price incentives and the perspective of forest logging companies, which are key forest players in the Congo Basin. This article shows that there would be no massive behavior change of logging companies, as this carbon price incentive effect—when it exists—is too weak.

NDC is a different paradigm as it relies more on political decisions than on market mechanisms. This paper provides a contribution to NDC elaboration, because knowing the opportunity cost of a ton of CO_2 not emitted can potentially help governments to allocate reduction efforts across sectors while minimizing impacts on their national economies. However, new research will be needed to check if this paradigm change will be sufficient to change actors' behaviors for reducing forest degradation in Central Africa.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jfe.2017.10.001.

References

IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (Eds.), Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY USA.

UNFCCC, 2011. Decision 1/CP.16. The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention. Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010–Addendum –Part Two: Action taken by the Conference of the Parties at its sixteenth session, 2–31, United Nations Framework Convention on Climate Change, 2011.

Angelsen, A., et al., 2012. Analysing REDD+: Challenges and choices. CIFOR, Bogor, Indonesia, pp. 456.

Chagas, T., et al., 2011. Nested Approaches to REDD+: An overview of issues and options, p. 50.

Karsenty, A., Tulyasuwan, N., de Blas, E.D., 2012. Financing options to support REDD+ activities, Report for the European Commission DG Climate Action.

Calmel, M., et al., 2011. REDD+ à l'échelle projet Guide d'évaluation et de développement. ONFI, Paris, 215 p.

Goldstein, A., Gonzalez, G., Peters-Stanley, M., 2014. Turning over a New Leaf: State of the Forest Carbon Markets 2014. Ecosystem Market Place.

Brown, S., et al., 2002. Changes in the use and management of forests for abating carbon emissions: issues and challenges under the Kyoto Protocol. Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences 360 (1797), 1593–1605.

Dixon, R.K., Schroeder, P.E., Winjum, J.K., 1991. Assessment of promising forest-management practices and technologies for enhancing the conservation and sequestration of atmospheric carbon and their costs at the site level, United States.

Durrieu de Madron, L., et al., 2011. Estimation de l'impact de différents modes d'exploitation forestière sur les stocks de carbone en Afrique centrale. Bois et Forêts des Tropiques 65 (308), 75–86.

Putz, F.E., et al., 2008. Improved Tropical Forest Management for Carbon Retention. PLOS Biology 6 (7), e166.

Timothy, R.H.P., Sandra, B., Felipe, M.C., 2014. Carbon emissions from tropical forest degradation caused by logging. Environmental Research Letters 9 (3), 034017.

Ndjondo, M., et al., 2014. Opportunity costs of carbon sequestration in a forest concession in central Africa. Carbon Balance and Management 9 (1), 4.

Healey, J.R., Price, C., Tay, J., 2000. The cost of carbon retention by reduced impact logging. Forest Ecology and Management 139 (1–3), 237–255.

Hansen, M.C., et al., 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342 (6160), 850–853.

OFAC, 2012. Etat des Forêts 2010. Les forêts du bassin du Congo, Office des publication de l'Union européenne.

Maniatis, D., et al., 2013. Financing and current capacity for REDD+ readiness and monitoring, measurement, reporting and verification in the Congo Basin. Philosophical Transactions of the Royal Society B: Biological Sciences 368 (1625).

Bayol, N., et al., 2012. Forest management and the timber sector in Central Africa, in The Forests of the Congo Basin –State of the Forest 2010. Office des publications de l'Union Européenne, Luxembourg.
Karsenty, A., et al., 2008. Regulating industrial forest concessions in Central Africa and South America. Forest Ecology and Management 256 (7), 1498–1508.
VCS, 2016. Agriculture, Forestry and Other Land Use (AFOLU) Requirements, version 3.4.
Griscom, B.W., Cortez, R., 2013. The case for improved forest management (IFM) as a priority REDD+ strategy in the tropics. Tropical Conservation Science 6 (3), 409–425.
Somorin, O.A., et al., 2012. The Congo Basin forests in a changing climate: Policy discourses on adaptation and mitigation (REDD+). Global Environmental Change 22 (1), 288–298.
WCS, 2011. Assessment of the Potential Carbon Financing of a REDD project in the Ngamikka (Kabobo) proposed protected area Eastern Democratic Republic of Congo.
Acworth, J.M., 2012. Project Information Document (Appraisal Stage) – Cameroon:NGOYLA MINTOM PROJECT – P118018. World Bank, Washington, D.C.
Strebel, R.J., 2013. North Pikounda REDD+ Project. Carbon Conservation Pte Ltd: VCS project database.
Freund, J.T., 2012. The Mai Ndombe REDD+ Project. ERA & Wildlife Works: VCS project database.
Tuttle, D., 2014. Isangi REDD+ VCS-CCB project description. Jadora & ecoPartners: VCS project database.
Bellassen, V., Gitz, V., 2008. Reducing Emissions from Deforestation and Degradation in Cameroon — Assessing costs and benefits. Ecological Economics 68 (1–2), 336–344.
Grondard, N., et al., 2013. Lutte contre la déforestation et aménagement forestier durable dans l'Etat du Mato Grosso –Municipalité de Cotriguaçu Etude de faisabilité. ONF International, Projet FORAFAMA, Paris.
TEREA, 2013. Concession REDD+ certifiées FSC du Haut-Nyong: Augmentation des DMA et certification FSC. CIFOR, Projet FORAFAMA 103 p.
Hirsh, F., et al., 2013. Projet pilote REDD+ de la Lukénie, in Projet FORAFAMA. CIFOR, Bogor, Indonesia, p. 111, 59p.
Medjibe, V.P., Putz, F.E., 2012. Cost comparisons of reduced-impact and conventional logging in the tropics. Journal of Forest Economics 18 (3), 242–256.
Telfer, M.A., Sharma, S.K., 2014. Methodology development and simulations for estimating greenhouse gas emission reductions from improved forest management with reduced impact logging. International Journal of Forest Engineering 25 (2), 124–137.
Putz, F.E., et al., 2012. Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. Conservation Letters 5 (4), 296–303.
Carret, J., Clement, J., 1993. La compétitivité des bois d'oeuvre Africains. Ministère de la Coopération, Paris.
Wilkie, D., et al., 2000. Roads: Development, and Conservation in the Congo Basin. Conservation Biology 14 (6), 1614–1622.
CTFT, 1989. Mémento du forestier. In: Centre Technique Forestier Tropical: Techniques rurale en Afrique. Ministère français de la Coopération et du Développement, pp. 1257.
ITTO, 2014. Tropical Timber Market Report. In: TTTO Market Information Service.
Brown, S., et al., 2005. Impact of selective logging on the carbon stocks of tropical forests: Republic of Congo as a case study, in Logging impacts on carbon stocks. United States Agency for International Development, Arlington, Virginia, USA.
Dupuy, B., 1998. Bases pour une sylviculture en forêt dense tropicale humide africaine FORAFRI, vol. 4. CIRAD-Forêt, Montpellier, France.
Fargeot, C., Forni, E., Nasi, R., 2004. Réflexions sur l'aménagement des forêts de production dans le bassin du Congo. Bois et Forêts des Tropiques 281, 19–34.
GOFC-GOLD, 2012. A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals associated with deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation. Reducing greenhouse gas emissions from deforestation and degradation in developing countries., pp. 219.
Eggleston, S., et al., 2006. Agriculture forestry and other land use, vol. 4. IPCC: Guidelines for National Greenhouse Gas Inventories.
Dhôte, J.-F., Impact, I.S., et al., 2016. Leviers forestiers en termes d'atténuation pour lutter contre le changement climatique. INRA, Paris, France, 95 p.
Djuikouo, M.N.K., et al., 2010. Diversity and aboveground biomass in three tropical forest types in the Dja Biosphere Reserve: Cameroon. African Journal of Ecology 48 (4), 1053–1063.
Medjibe, V.P., et al., 2011. Impacts of selective logging on above-ground forest biomass in the Monts de Cristal in Gabon. Forest Ecology and Management 262 (9), 1799–1806.
Gourlet-Fleury, S., et al., 2013. Tropical forest recovery from logging: a 24 year silvicultural experiment from Central Africa. Philosophical Transactions of the Royal Society B: Biological Sciences 368 (1625).
Lewis, S.L., et al., 2013. Above-ground biomass and structure of 260 African tropical forests. Philosophical Transactions of the Royal Society B: Biological Sciences 368 (1625).
Djomo, A.N., Knohl, A., Gravenhorst, G., 2011. Estimations of total ecosystem carbon pools distribution and carbon biomass current annual increment of a moist tropical forest. Forest Ecology and Management 261 (8), 1448–1459.
Preece, N.D., et al., 2012. Comparing above-ground biomass among forest types in the Wet Tropics: Small stems and plantation types matter in carbon accounting. Forest Ecology and Management 264 (0), 228–237.
Gourlet-Fleury, S., et al., 2011. Environmental filtering of dense-wooded species controls above-ground biomass stored in African moist forests. Journal of Ecology 99 (4), 981–990.
Henry, M., et al., 2010. Wood density: phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. Forest Ecology and Management 260 (8), 1375–1388.
Durrieu de Madron, L., Fontez, B., Dipapoundji, B., 2000. Dégâts d'exploitation et de débardage en fonction de l'intensité d'exploitation en forêt dense humide d'Afrique Centrale. Bois et Forêts des Tropiques 54 (264), 57–60.
Ndassa, A., 2010. Evaluation post exploitation et incidence sur la dynamique forestière. Cas des UFA10. 30-10.031 au Cameroun. Université de Yaoundé I, p. 84.
Pallisco, 2012. Rapport de clôture d'exploitation de l'AAC n(3 des UFA 10-030 et 10 031 regroupées. Cellule inventaire d'aménagement, Pallisco, p. 16.
Cerutti, P.O., Lescuyer, G., 2011. The domestic market for small-scale chainsaw milling in Cameroon: present situations, opportunities and challenges, in Occasional Paper 61. CIFOR, Bogor, Indonesia.
Eba'a Atyi, R., 1998. Cameroon's Logging Industry: Structure, Economic Importance and Effects of Devaluation, in Occasional Paper 14. CIFOR.
FAO, 1998. A Manual for the Planning, Design and Construction of Forest Roads in Steep Terrain, vol. W8297. Forestry Department, Rome.
Brimont, L., 2014. The cost of Reducing Emissions from Deforestation and forest Degradation (REDD+) in Madagascar. AgroParisTech.
Carter Ingram, J., et al., 2009. REDD Project Development Guide. WCS.
Chenost, C., et al., 2010. Les marchés du carbone forestier. UNEP, ONFI, AFD, BioCF, Paris, 172 p.
VCS, 2008a. Tool for AFOLU methodological issues. Voluntary Carbon Standard.
White, D., Minang, P., 2011. stimating the opportunity costs of REDD+ A training manual. World Bank Institute, Washington, p. 262.
VCS, 2008b. Tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination. Voluntary Carbon Standard.
Halsnæs, K., et al., 2007. Framing issues. In: B.D, Metz, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Climate Change 2007: Mitigation. Cambridge University Press, Cambridge, pp. 118–167.
Harrison, M., 2012. Valuing the Future: the Social Discount Rate in Cost-Benefit Analysis. Australian Government, Canberra, Visiting Researcher Paper.
Hofstad, O., Araya, M.M., 2015. Optimal wood harvest in miombo woodland considering REDD+. A case study at Kitulangalo Forest Reserve: Tanzania. Forest Policy and Economics 51 (0), 9–16.
COP21, 2015. Paris agreement. United Nations, Paris, p. 27.
Guitet, S., 2011. Production de bois-énergie sur un massif forestier dédié à cette vocation en Guyane. Etude de cas en forêt de Balata Saut-Léodate (Guyane Française). ADEME, ONF, Cayenne, French Guiana.
Karsenty, A., 2007. Overview of Industrial Forest Concessions and Concession-based Industry in Central and West Africa and Considerations of Alternatives. Congo Basin Forest Partnership, Kinshasa http://pfbc-cbfp.org/tl_files/archive/thematique/Forest_Concessions_and_Concession_Industry_Central.pdf.