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ECONOMIC ANALYSIS OF PROPOSED TREE TENURE REFORM IN GHANA

INTEGRATED LAND AND RESOURCE GOVERNANCE TASK ORDER UNDER THE STRENGTHENING TENURE AND RESOURCE RIGHTS II (STARR II) IDIQ

Contract Number: 7200AA18D00003/7200AA18F00015
COR: Stephen Brooks
USAID Office of Land and Urban
Contractor Name: Tetra Tech
Author(s): Yaw Adarkwah Antwi, Bright Kumordzi, Meyru Bhanti, Alexandre Grais, and Robert O'Sullivan

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Cover Photo: A shade tree tagged for carbon stock analysis in Asankrangwa Stool, Ghana. ILRG/Ghana

Tetra Tech Contact(s): Megan Huth, Project Manager
159 Bank Street, Suite 300
Burlington, VT 05402
Tel: (802) 495-0282
Fax: (802) 658-4247
Email: megan.huth@tetratech.com

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Submission Date: 16 September 2022
Submitted by: Melissa Hall
Tetra Tech
159 Bank Street, Burlington VT 05401, USA
Tel: (802) 495-0282
Fax: (802) 658-4247

Contract Number: 7200AA18D00003/7200AA18F00015
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DISCLAIMER

TABLE OF CONTENTS

LIST OF ACRONYMS

CRIG	Cocoa Research Institute of Ghana
ERPD	Emission Reduction Program Document
FC	Forestry Commission
FCPF	Forest Carbon Partnership Facility
FSD	Forest Services Division
GHC	Ghanaian Cedi
LIF	Lumber Information Form
LMCC	Log Measure and Conveyance Certificate
OASL	Office of the Administrator of Stool Lands
TIDD	Timber Industry Development Division
TIF	Tree Information Form
FLR	Forest Landscape Restoration

1.0 EXECUTIVE SUMMARY

Government ownership and control of all "naturally occurring" timber trees on public and private land in Ghana is a contributing factor to illegal deforestation and a challenge to planting trees. Continued deforestation and reduced tree planting makes it harder for Ghana to meet its climate targets under the Paris Agreement to generate 23.5 million emission reductions from "gender-responsive sustainable forest management" between 2020 – 2030, which is expected to require $392 million in funding (MESTI, 2021). This assessment, prepared as a part of the USAID Integrated Land Resources and Governance (ILRG) program's Supporting Deforestation-Free Cocoa in Ghana activity, reviews the economic impact of a proposed tree tenure policy reform in Ghana that transfers full ownership of all trees to farmers and landowners. The audience for this assessment is the Forestry Commission (FC) and other stakeholders in the forest sector in Ghana.

State ownership of naturally occurring trees is widely considered a strong disincentive for landowners and smallholders to nurture trees, regardless of land tenure. To improve tree tenure security, the government is piloting a requirement that farmers register any tree that they plant to demonstrate that it is not naturally occurring. This is an unworkable policy solution and serves as an additional hurdle that disincentivizes tree planting (Fischer et al., 2020; Kyere-Boateng, 2021). This policy regime of government ownership is a contributing factor to declining timber volume over recent decades, with an annual 3.4 percent decline (Figure 1 and Table 10), and low stumpage fees collected from off-reserve timber as compared with on-reserve timber (Figure 2).

Figure 1: National Volume of Timber Extracted Off-Reserve from 1998 to 2015

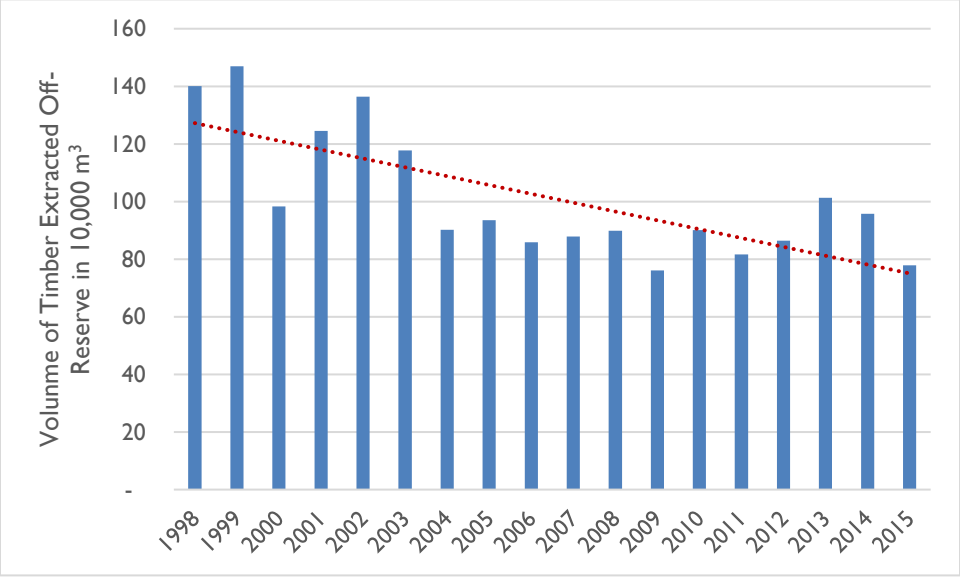
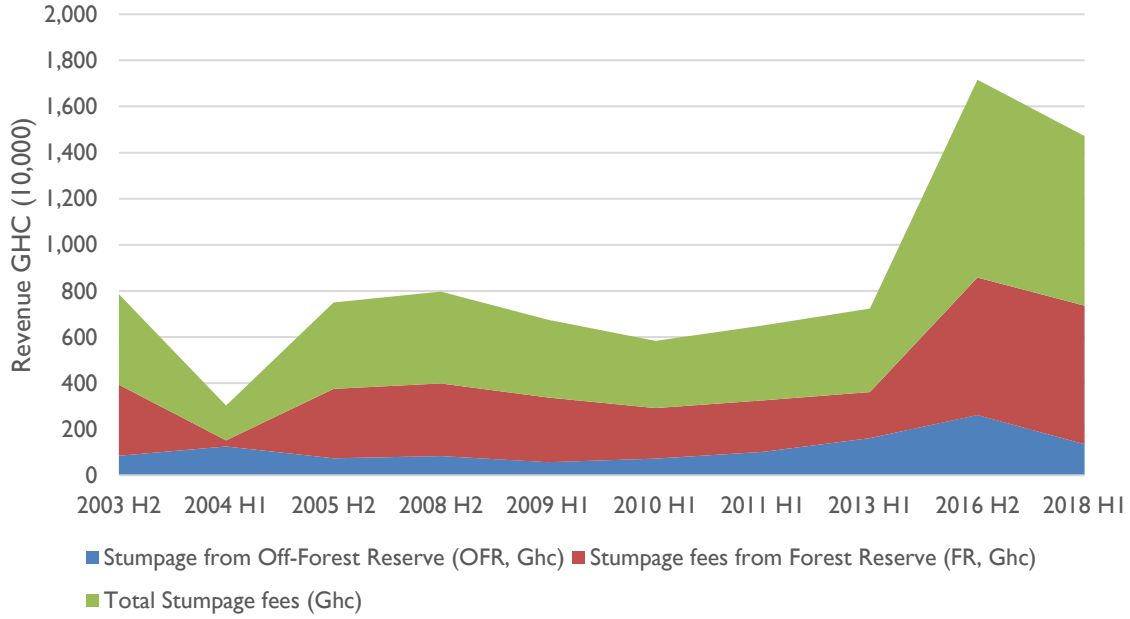


Figure 2: National Proportion of Revenue from Stumpage Fees from On and Off Forest Reserves



Fischer et al., 2020, recommend a tree tenure policy reform to help address this: *transfer full ownership of all trees off-reserve to farmers and landowners*. It is expected that such a shift in the tree tenure regime would create incentives for farmers and landowners to plant and/or nurture and maintain naturally occurring trees on their lands. But such a shift would lead to immediate changes in revenues and incomes that currently flow to the government through the Forestry Commission (FC).

The FC currently generates revenue from three sources of taxes and levies: 1) stumpage fees, 2) log measure and conveyance certificate (LMCC) fees and 3) export fees. Using the 2018 half-year stumpage fee value, the FC's share of stumpage fees collected from off-reserve timber harvested, 677,936.60 Ghanaian cedis (GHC), makes up between 9.6 and 11.2 percent of total revenue from off-reserve timber harvested (Table 7). The proposed policy reform would remove stumpage fees for off-reserve timber, but the FC would continue to gather income from LMCC and export fees – the source of the bulk of government revenue.

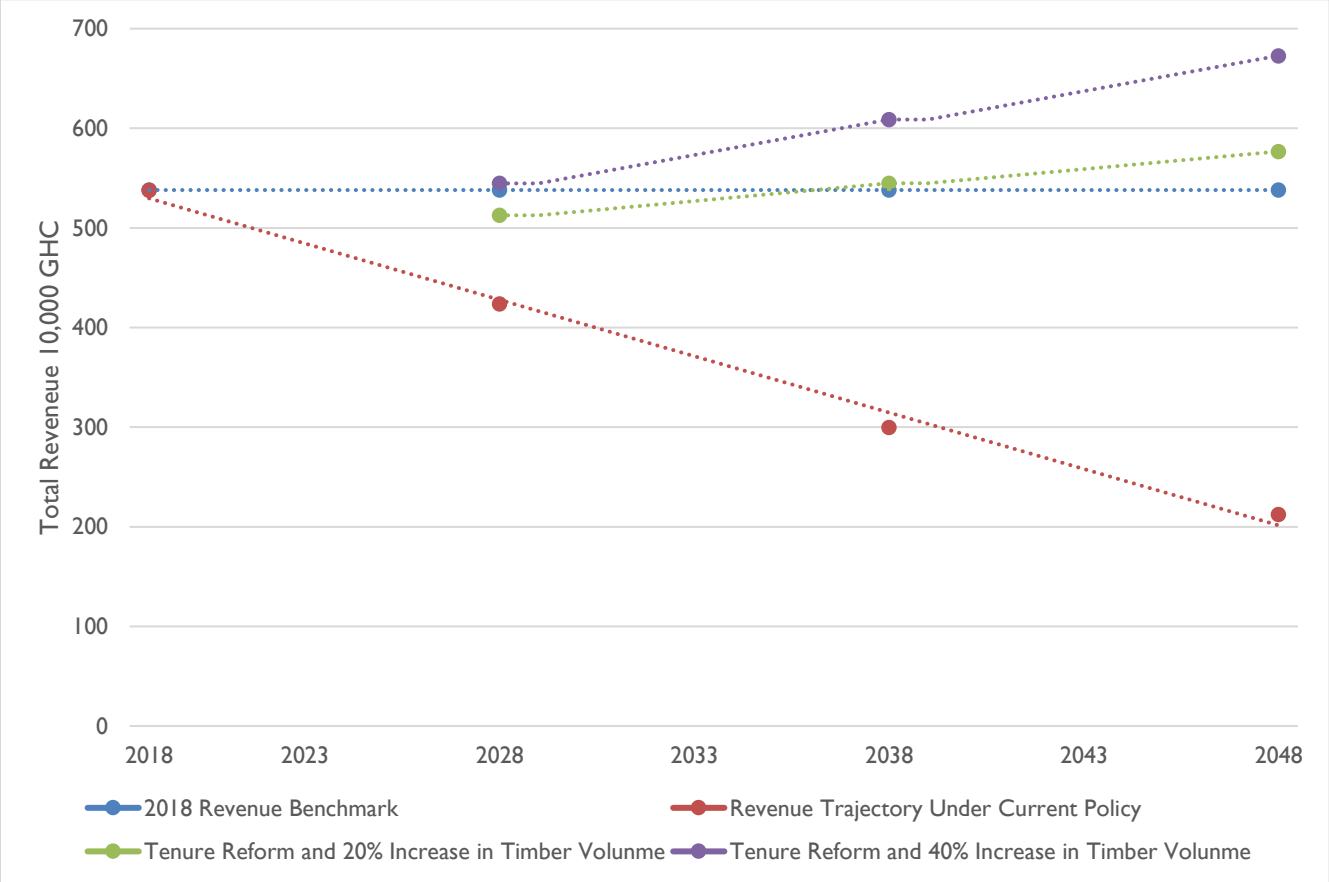
This assessment reviews the potential economic impact of a proposed tree tenure policy reform in Ghana that would transfer ownership rights of naturally occurring trees off-reserve from the government to farmers and landowners. The authors of this assessment calculated the potential near-term loss of income from a shift in policy and weighed it against the projected long-term decline of timber sources if the policy is not reformed. This provided realistic estimates of immediate revenue losses to the FC and projected long-term outcomes.

This assessment considered two scenarios of change resulting from the policy reform: a 20 percent and a 40 percent timber volume increase derived from an increase in tree-planting triggered by the devolution of tree title. The increase in volume was calculated based on the total area of lands with potential to support timber trees and found that if the incentive exists for farmers to increase tree cover off-reserve, available timber for harvest could increase from 134,368 m^3 to potentially 188,115 m^3 across Ghana in the next 30 years. This could generate between 674 million to 787 million tons of CO_2 sequestered in 20 years under the low or high scenarios respectively.

In contrast, under the current timber trajectory the total annual revenue from timber harvest is projected to decrease from GHC 5.3 million in 2018 to GHC 97,000 over the next 30 years without

policy reform, which represents a 30 percent revenue loss. However, if the policy is reformed and stumpage fees, which place an undue burden on farmers and landowners, are abolished, then the FC is estimated to see a slight initial revenue decrease compared to 2018 revenue (decrease to GHC 5.1 million) through 2028 under the low scenario – but this is still higher than expected future revenue of GHC 3.3 million which takes into account declining stocks without policy reform. Under the high timber scenario, FC revenue could increase to over GHC 6 million in 30 years. Each estimation assumes that under the proposed policy reform tenure and policy barriers to tree planting and natural tree growth would be eliminated, and farmers and landowners would be incentivized to grow and protect timber species on their land (Fischer et al., 2020). This could be boosted by government or private sector initiatives that supported tree planting. Increasing the number of trees would also benefit local communities by providing them with more economic opportunity to profit from the timber on their land.

Figure 3: Total Revenue Projected for the Next 30 Years with the Current Policy without Reform to the Stumpage Fees Collected and Projected Revenue from a Policy Change and Predicted Revenue Changes



The gains in revenue that would result from the proposed reforms more than offset initial losses of stumpage fees that the FC would sustain. At the same time this would generate significant greenhouse gas reductions – making it an extremely cost-effective method for Ghana to achieve its Paris Agreement targets while supporting cocoa farmers and local communities.

2.0 BACKGROUND

Government ownership and control of all "naturally occurring" timber trees, on public and private land is a contributing factor to illegal deforestation and a challenge to planting trees in Ghana. State ownership of naturally occurring trees is widely considered a strong disincentive for landowners and smallholders to nurture trees, regardless of land tenure (Fischer et al., 2020; Kyere-Boateng, 2021; Kroeger, 2017). In its updated Nationally Determined Contribution under the Paris Agreement, the Government of Ghana has committed to generate 23.5 million emission reductions from "gender-responsive sustainable forest management" between 2020 and 2030, which is expected to require $392 million in funding (MESTI, 2021). Increasing tree cover is an important tool to help reduce emissions and mitigate some of the impacts of climate change that are already felt throughout Ghana (Ministry of Foreign Affairs of the Netherlands, 2018). Increased drought and rising temperatures particularly threaten the cocoa industry, which is the backbone of the regional economy (Bunn, 2018; Enriquez 2020; O'Sullivan & Vanamali, 2020). Without systematic adaptation, Brunn et al. (2018) estimate that the mean cost of climate change to the cocoa sector will be $270 – 660 million per year by 2050.

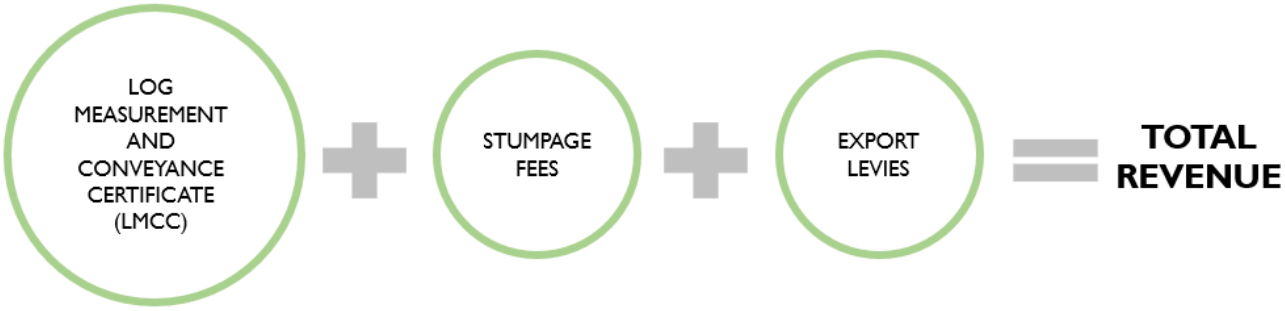
This assessment, prepared as a part of the USAID Integrated Land Resources and Governance (ILRG) program's Supporting Deforestation-Free Cocoa in Ghana activity, reviews the economic impact of a proposed tree tenure policy reform in Ghana that transfers full ownership of all trees to farmers and landowners. As a result of this reform, the FC would lose the stumpage fees it collects as owner of these trees. Stumpage levies are fees paid to the FC when timber is brought to market, as under the current policy the government has ownership rights over all off-reserve naturally occurring trees. It is expected that such a shift in tree tenure regime would create appropriate incentives for farmers and landowners to plant trees, and/or nurture and maintain naturally occurring trees on their lands instead of destroying them, as anecdotal evidence reports is happening under the existing policy. Such a shift would also lead to immediate changes in revenues that currently flow to government through the FC; it is therefore important that the near-term impacts of removing stumpage levies are weighed against longer-term impacts of maintaining the current tree tenure policy.

2.1 SOURCES OF TIMBER REVENUE AND FOREST CATEGORIES

2.1.1 SOURCES OF TIMBER REVENUE

The FC currently receives revenue from three areas: 1) stumpage fees; 2) fees from issuing a log measure and conveyance certificate (LMCC), and 3) export levies from timber on- and off-forest reserves (Figure 4). The proposed policy change would put ownership of the trees into the hands of the farmers and landowners and remove the revenue from stumpage levies outside forest reserves. The FC would continue to receive revenue from LMCC and export levies from timber from both forest reserve and non-forest reserve and stumpage fees from timber on forest reserves. Each is a levy or tax exacted at different stages of the timber harvest process. Stumpage fees are the taxes associated with bringing the timber to market. The LMCC is exacted when a certificate of assurance is issued confirming the tree volume has been properly documented in the tree information form (TIF) and lumber information form (LIF), and the export tax is applied when the timber is exported. Recent laws requiring all government projects to source timber nationally has led to a decrease in timber exports and the money generated from export levies, while the revenue from stumpage fee and the LMCC make up an increased proportion of the total revenue to the FC. Full definitions of these levies and taxes are provided in Section 3.2.1.

Figure 4: Revenue Pools for the FC



The Ghanaian constitution details how "revenue accruing from stool lands" is divided (Article 267(6)). This applies to how the share of revenue from stumpage fees from off-reserve areas is allocated to the FC, Office of the Administrator of Stool Lands (OASL), the traditional authority, the stool, and the district assembly. As shown in table 1, the district assembly receives about 25 percent of the total stumpage revenue generated. However, this is only a small fraction of their total revenue and should represent a significant loss of revenue to the district assemblies. Given the institutional weight of the FC regarding how tree tenure is managed and the fact that the FC retains the largest share of stumpage fees, the authors focused their analysis on how devolution of tree tenure and consequential loss of stumpage fees would affect the FC. It is also important to note that the proposed tree tenure policy reform focuses on off-reserve lands – FC and the other stakeholders would still receive revenue from timber harvested from forest reserves.

Table 1. Share of Off-Reserve Stumpage Fees Received by Each Qualifying Institution in Ghana

	Stage 1: Share of Total		Stage 2: Share of 50% Among Qualifying Institutions (1992 Constitution)				
	FC	OASL and others		OASL	Traditional Authority	Stool	District Assembly
	50%	50%	Of the 50%	10%			
			Of the remainder after OASL's share		20%	25%	55%
Equivalent Share of Total Stumpage	50%			5%	9%	11.3%	24.8%

2.1.2 CATEGORIES OF TIMBER SOURCES IN GHANA

Revenue is generated from five different timber sources throughout Ghana. Table 2 provides a description of the different timber source types (NepCon, 2017). The equations used to calculate the annual timber harvested consider the volume and value of timber from the off-reserve sources.

Table 2: Sources of Timber in Ghana

Timber Source	Explanatory Notes
Natural forest in forest reserves	Natural forest within Ghana's forest reserves (permanent forest estates). These forests are on stool/skin lands and owned by chiefs but are vested in Ghana's President and managed by the FC
Natural forest off forest reserves	Natural forest outside of Ghana's forest reserves, on land owned by chiefs, families, individuals, and public institutions.

Plantation in forest reserves	Plantation within Ghana's forest reserves (permanent forest estates). Plantations established by the FC are managed by the FC, whereas private plantations are under special benefit sharing arrangements with investors
Plantation off forest reserves	Plantations outside forest reserves, on lands which may be owned by stool (community), family, individuals or public institutions. The plantations are privately managed, and the FC conducts monitoring and issues the plantation production certificate
Submerged forest	Underwater forests (i.e., submerged in a dam's reservoir), off-reserve, on stool and family lands. Timber harvesting rights are granted by the FC through underwater use rights and salvage permits.

2.2 THE NEED FOR REFORM

The current tenure regime which allows the government to lay claim to all naturally occurring trees regardless of private ownership of the land has two main challenges: 1) the declining timber volume over recent decades, and 2) the low stumpage fees collected from off-reserve timber as compared with on-reserve timber.

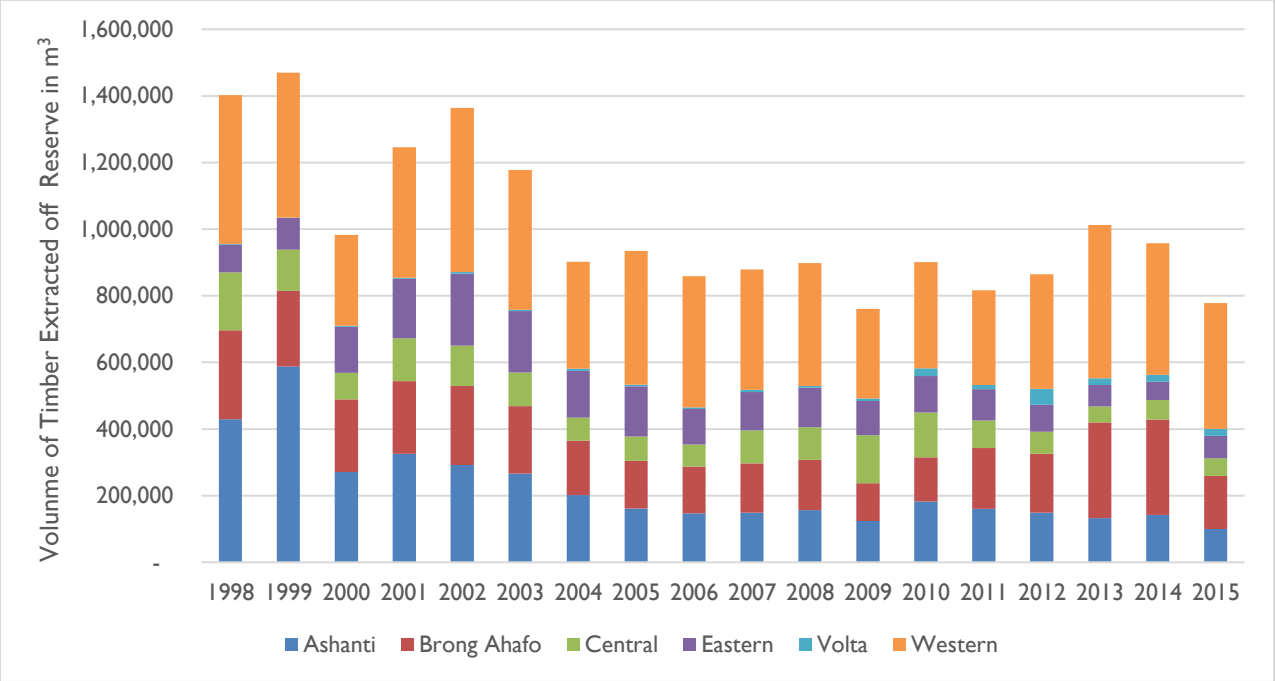
2.2.1 DECLINING TIMBER VOLUMES

From 1998 to 2015, Ghana has seen a dramatic decrease in the amount of timber extracted (see Figure 5, and Table 10 in Annex I). In absolute terms, the 1.4 million m^3 of timber extracted in 1998 decreased to 778,226 m^3 by 2015. This is the equivalent of a steady decline of 3.4 percent per year over the 17-year period.

A compound rate of 3.4 percent will be applied to future projections to make comparative estimates of revenue gains/losses in reform and no reform scenarios.

The pressures of declining timber stocks are not felt uniformly across the country. For example, in the Ashanti Region, timber extraction fell by 77 percent from 1998 to 2015, while in the Western Region timber extraction only fell by 15 percent over the same period. Without modification of the current tree tenure regime, there will likely continue to be a decline in timber stocks in the future.

Figure 5: Total Volume of Timber Extracted Off-Reserve from 1998 – 2015



2.2.2 LOW STUMPAGE FEES

Based on the figures compiled from the FC and OASL reported in Table 3, off-reserve timber currently makes up on average 27 percent of the total annual revenue from stumpage fees (FC & OASL, 2003, 2004, 2005, 2008, 2009, 2011, 2016, 2018). The recommended reform to the tree tenure policy would transfer full ownership of trees off-reserve to farmers and landowners, stumpage fees from **on-reserve forests would remain in place, meaning roughly three quarters of the annual revenue from stumpage fees would be unchanged.** The question becomes if the projected gains in revenue from reform can offset the 27 percent loss in revenue from off-reserve stumpage fees.

Table 3: Data on Stumpage Fees for Selected Years, Compiled from OASL Publications of the Reported Dates

Year*	Stumpage Fees from Off-Forest Reserve (GHC)	Stumpage Fees from Forest Reserve (GHC)	Total Stumpage Fees (GHC)	Percent of Total Stumpage Fees from Off-Forest Reserve
2003 H2	853,261	3,075,178	3,928,439	22%
2004 H1	1,249,412	264,656	1,514,068	83%
2005 H2	733,739	3,012,975	3,746,714	20%
2008 H2	836,682	3,147,112	3,983,795	21%
2009 H1	569,142	2,806,690	3,375,832	17%
2010 H1	722,685	2,192,572	2,915,257	25%
2011 H1	1,015,978	2,231,751	3,247,730	31%
2013 H1	1,608,623	2,008,200	3,616,823	44%
2016 H2	2,618,663	5,961,483	8,580,146	31%
2018 H1	1,355,873	6,001,616	7,357,489	18%

*Note: (H1= first half of the year, H2 = second half of the year)

Off-reserve stumpage fees constitute only a small fraction of total revenue from stumpage fees. Coupled with a steadily declining volume of off-reserve timber, this paints a challenging picture for the projected revenues from stumpage fees off-reserve into the future.

3.0 METHODOLOGY

The proposed policy reform would transfer full ownership of naturally occurring trees off-reserve from the FC to farmers and landowners who nurture and maintain the trees on their lands. This means all trees are owned by landowners and we assume all naturally occurring trees are treated the same as off-reserve plantation timber for the purposes of estimating government revenue from off-reserve tree harvesting. The objective of this analysis is to determine potential fluctuations in income and revenue for all FC departments under such a policy. This was done in two parts:

1) **Develop plausible scenarios of tree cover increases** (and by implication timber volume increases) that could be triggered by a tree tenure policy change that transfers ownership to farmers and landowners. This will demonstrate the time frame of increases in FC income that will eventuate and offset any immediate losses.

2) **Establish total income to FC under the current regime** for off-reserve timber harvesting and estimate the total income to FC if the regulatory regime is changed as proposed, to provide a clear perspective on the income implications to FC of the policy shift. As noted above, the analysis focused on the impacts on the FC as the largest recipient of stumpage fees and their importance in reform.

3.1 DEVELOPMENT OF PLAUSIBLE SCENARIOS OF TREE COVER INCREASE POTENTIAL

3.1.1 KEY ASSUMPTIONS

A key assumption of the change in tree tenure policy is that devolving tree ownership and eliminating the tree registration policy removes key barriers and will incentivize farmers and landowners to nurture and care for trees on their land, and this would result in an increase in the number of trees in Ghana. This assumption is informed by research and evidence from other countries found in Fischer et al., 2020. Over time a combination of planting and allowing the growth of naturally germinating trees should increase shade trees in cocoa farms and trees across Ghana more broadly and address the current issue of the declining timber volume over the long term.

The off-reserve land types assessed for this study include open forest, closed forest, shaded cocoa, and non-shaded cocoa (Table 4 and Figure 6). Within some ecoregions of Ghana (see Figure 7), such as savannah, open forest is naturally sparse, so this assessment's scenarios assume that most of the trees will be planted on degraded open forest areas where an increased density of trees is viable. We do not assume afforestation beyond naturally occurring tree densities which would not be ecologically sound. We also conservatively assume that closed forests are not suitable for additional tree planting or natural regeneration. While most of the increase in timber harvested will be from open forest areas, the authors considered an additional scenario in which shade trees on cocoa farms are expanded to provide benefits both to the farmer and the FC. For a cocoa farm specific analysis, see Box 1. The authors excluded annual crops, other tree crops, bare land, and settlements, as tree cover was not expected to increase on these land covers. Off-reserve submerged forests or wetland forests are not broken down as a separate category because they are incorporated into open and closed forest based on the density of the canopy cover. The mangrove class was also excluded to keep the estimates conservative. These land cover types were determined based on the land classification defined by the FC in their Emission Reduction Program Document (ERPD) submission to the Forest Carbon Partnership Facility (FCPF) and a landcover map produced by the FC for 2018 (Ghana Forestry Commission Resource Management Support Centre, 2021).

Figure 6: Land Use Cover Types, Ghana 2018

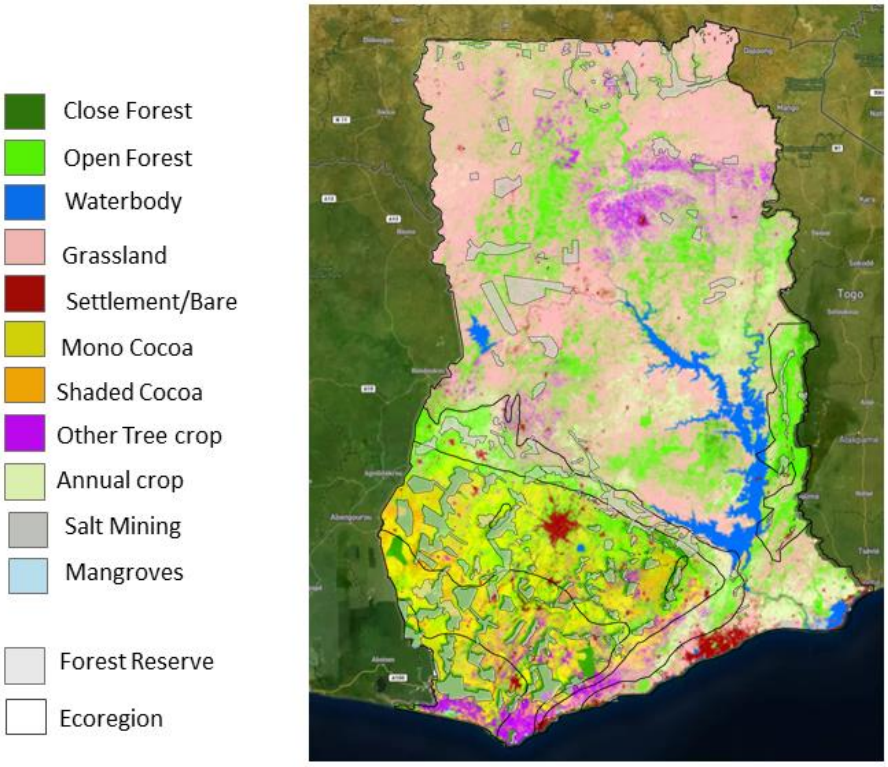


Figure 6: Ecoregions of Ghana

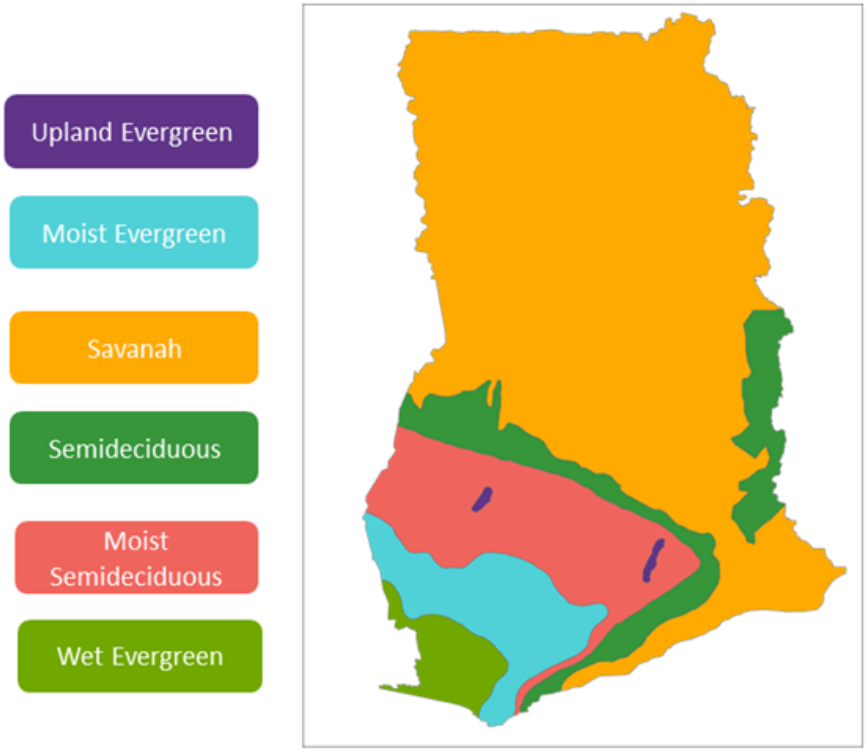


Table 4: Land Cover Classes and Tree Density in Ghana

Strata	Total Area (ha)	Area Off-Reserve (ha)	Estimated Current Tree Density (# of trees/ha) or Canopy Cover
Open forest [1]	5,234,425	4,674,051	Species dependent - 15%-60%
Closed forest	1,236,016	374,140	Species dependent - >60%
Shaded cocoa	378,405	355,071	Farm dependent 10%->40%
Non-shaded cocoa	1,882,699	1,785,101	Farm dependent 0%-<10%
Grassland	9,951,137	9,314,820	Scattered trees - <10% canopy coverage according to national forest definition.
Other tree crops[2]	1,128,831	38,425	Non shade systems

Because data for timber value extraction was not available, the 2018 half-year stumpage fee value was used to establish a baseline timber volume that was extracted from non-reserve forests. The FC classifies timber species according to their market strength and status of inventory into three classes: high, medium, and low. Through collaboration with experts in the Timber Industry Development Division (TIDD) in Suyani and Takoradi, an assumption was made on the ratio of timber from each stumpage class. A ratio of 20 percent high stumpage class (S1), 50 percent medium stumpage class (S2), and 30 percent low stumpage class (S3) was applied to the estimated volume of each stumpage class (S1 = 58.32Ghc/m^3; S2 = 28.57Ghc/m^3 and S3 = 10.48Ghc/m^3) to calculate a 67,184.5 m^3 of timber harvested in the half-year, which translates to 134,368 harvested over the year.

3.1.2 SCENARIOS

For the purposes of this study, the authors assume two scenarios of increased canopy cover in certain open forests and cocoa farms if tree rights are transferred to farmers and this transference of ownership leads to an increase in the density of timber trees.

Forests in Ghana cover roughly 6.5 million ha with most forest, including open and closed forest, 78 percent of which are found off-reserve (Table 4). In the ERPD, open forest is defined as 15 – 59.9 percent canopy cover and closed forest is defined as more than 60 percent canopy cover. This analysis considers a low and a high scenario in which there would be a 20 or 40 percent increase in canopy cover that results in a corresponding increase in timber harvests on open forests within the moist evergreen ecoregion. The analysis assumes that most of the trees will be planted or regrow in degraded open forest in the moist evergreen ecoregion where an increased density of trees is aligned with the native forest density and thus viable and appropriate. The high scenario was selected as the plausible upper range to transition open forest to closed forest. We note that a 40 percent increase in canopy cover of the lower bounds of the open forest will still result in the forest remaining classified as open-forest, and a 40 percent increase in the upper bound of open forest will still result in less than 100 percent canopy cover. The analysis excludes potential increases in open forest in the savannah ecoregion because savannah open forest is naturally sparse and increasing tree density would not be sound ecological practice and may cause negative impacts on biodiversity.

[1] Assuming that savannah ecoregions are naturally sparse, and it is not viable to increase planting in these regions, they are excluded, and 1,816,091 ha of open forest is considered for planting.

[2] e.g., cashew, shea, mango, coconut, rubber and oil palm

3.1.3 PROJECTIONS

Table 5 shows the estimated increase in timber harvest for low and high scenarios of planting off-reserve.

Table 5: Estimated Increase in Tree Cover if Tree Rights are Devolved to Farmers

Scenario	Baseline Timber Harvested	Scenarios Studied for Each Land Cover	Estimated timber harvest m^3 per year[3]
Low	134,368 m^3	Increase by 20%	161,242 m^3
High	134,368 m^3	Increase by 40%	188,115 m^3

Given the scenarios presented above, if the incentive exists for landowners to increase tree cover off-reserves, available timber could increase around 16 percent from 161,242 m^3 to approximately 188,115 m^3 across Ghana over 30 years. This volume includes a small percentage of timber from cocoa farms and assumes that timber from cocoa farms will continue to make up a small proportion of timber harvested annually after devolution of tree tenure, even if more shade trees are planted across cocoa farms. This analysis assumes that the distribution of timber harvested across ecoregions will reflect the 2018 harvest upon which we based the timber volume numbers. The 2018 harvest values come from all non-reserve forests and are not broken down by ecoregion. Also, it is important to stress that the actual number of trees that can be harvested over a given time will depend on the standing stock of the trees and the rate at which the trees regrow, both of which are dependent on local conditions and species. Our analysis uses a general species linear growth rate. This is to ensure that the amount of timber that is extracted does not exceed that area's long-term ability to supply timber (ITTO, 2015).

[3] The estimated increase in AAC was calculated by multiplying the average volume of a timber tree in Ghana by the total number of additional timber trees expected within each scenario. The following equation was applied to estimate volume in m3: Volume = π × (DBH / 200)^2 × H × 0.5 where DBH is diameter at breast height (cm) and H is height (m) (Henry et al., 2011). DBH and H for different timber species in Ghana was provided in Aabeyir et al., 2020. The resulting estimated volumes of each different species was averaged to come up with the average volume of a timber tree in Ghana (0.21 m^3/tree).

Box 1: Tree Planting Potential on Cocoa Farms

Agroforestry offers great benefits per ha both economically and environmentally (IUCN, 2020). Cocoa farms currently contribute a small amount to annual timber harvest. Current extraction of timber can be very damaging to cocoa farms as farmers do not decide when timber trees are cut and logging in productive cocoa farms damages cocoa trees. A tree tenure reform that gave ownership of trees to farmers could in the long term promote more timber grade species to be grown, as shade trees on cocoa farms can be harvested by farmers in cycles that fit with the replanting the underlying cocoa farm ever 25 – 50 years. To estimate these scenarios, we first considered the current area of cocoa farm and the current shade tree density. Each of the areas are based on the Ghana National Land Use Map of 2019.

Shaded tree density on cocoa farms varies greatly. A 2010 Cocoa Research Institute of Ghana (CRIG) study estimated that shade tree density varies from a low coverage of 5 – 6 trees/ha, medium coverage of 15 – 18 trees/ha, and high shade coverage of 22 – 30 trees/ha (CRIG, 2010) and recommends a 30 – 40 percent canopy, which they translate to 16 – 18 mature shade trees per ha. Research has shown that in some climate zones the shade tree density can be increased up to 25 – 50 trees/ha to help cocoa farms adapt to climate change in certain regions (Asare, 2019).

A literature review of papers that cover over 1,500 sample points across the cocoa growing area found a weighted average to establish a baseline shade tree density of 10.6 tree/ha (Table 13 in Annex 2). Ecom Agroindustrial Corp., a cocoa company active within the Western Region of Ghana, shared an additional estimate of baseline shade cover of the number of trees/ha (see Table 14 in Annex 2). A majority of the farms (73 percent) had a shade tree density of 1 to 10 trees/ha. The number of trees/ha were given as a range, assuming that the true average number of trees is halfway between that range (with a normal distribution). This would give 73 percent of the farms measured an average shade tree density of 4.9 trees/ha. This is significantly lower than the average value derived from the literature (10.6 trees/ha). The baseline shade tree density on shaded cocoa farms is assumed to be 10.6 trees per ha, which is conservative in our analysis, and non-shaded cocoa farms is assumed to be 0 trees per ha. While it is possible that monocultured farms could have scattered trees within their fields, we did not identify any studies with the number of shade trees on non-shaded farmland.

If there was a shift in tree tenure policy supported by direct efforts to tree planting on cocoa farms there could be additional timber sources in the future. For this analysis, the authors provide a low and a high scenario for both shaded and non-shaded cocoa farms, in which all cocoa farms would increase tree density to 25 trees/ha (low) and 50 trees/ha (high) - see Table 6.

Table 6: Estimated increase in tree cover on cocoa farms if tree rights are devolved to farmers

Scenario	Baseline Strata	Baseline Tree Cover	Scenarios Studied per Landcover	Area Off-reserve (ha)	Estimated Potential Increase in Timber Harvest m^3
Low	Shaded cocoa	10.6 tr/ha	From 10 trees per ha to 25	355,071	1,073,735
Low	Non-shaded cocoa	0 tr/ha	Increase from 0 trees per ha to 25	1,785,101	9,371,780
High	Shaded cocoa	10.6 tr/ha	From 10 trees per ha to 50	355,071	2,937,857
High	Non-shaded cocoa	0 tr/ha	Increase from 0 trees per ha to 50	1,785,101	18,743,560

3.1.4 ESTIMATED VOLUME OF HARVESTED TREES OVER 30 YEARS

The FC is understandably resistant to policy reform that may result in a loss of revenue. It is therefore important to quantify the loss of FC's share of stumpage (40 percent of stumpage fees) that would result from the proposed tree tenure reform and the extent to which timber volume increases may offset this.

To calculate the forecast in increased timber and associated revenue estimates associated with devolution of tree tenure, the authors applied the estimate of the timber volume forecast for 30 years reported for off forest reserve areas including open forest, shaded cocoa, and non-shaded cocoa, calculated in the section above (see Table 5). From this annual timber volume estimates for both the low and high scenarios were calculated and then scaled by 50 percent for the half-year estimate since the stumpage revenue information used in these estimates are reported half yearly (Table 7). The low scenario would yield a 120 percent increase in timber yield from the 2018 half year volume of 67,184m^3 to 80,620.80 m^3 and the high scenario would increase the timber volume by 140 percent. The scenario below includes a small percentage of timber from cocoa farms and does not consider the potential from the additional planting on cocoa farms outlined in Box 1. The authors conservatively assume cocoa farms would be reluctant to regularly log shade trees, and this will continue to make up a small portion of the total off-reserve timber harvested over the 30-year period considered.

Table 7: Forecast of Increases in Timber Volumes After Policy Reforms

Project Scenario	Land Use Type/Strata	Estimated Volume of Trees (m^3)
Low	Off-reserve timber volume in 30 years	4,837,248
	Annualized volume of timber harvest	**161,242**
	Half-year timber harvest*	**80,621**
High	Off-reserve	5,643,456
	Annual volume of timber harvest	**188,115**
	Half-year timber harvest*	**94,058**

**Values used in the computation*

3.2 ESTABLISHING TOTAL INCOME TO FC FROM THE CURRENT REGIME AND THE PROPOSED POLICY

Because the loss of FC claims to stumpage fees from harvesting naturally occurring trees off-reserve is a barrier to reform, effective policy reform needs to demonstrate a net gain in revenue over the long term (Fischer, 2020). The analysis estimates the proportion of total revenue to FC using the four scenarios below:

1. Current tenure policy and timber volume in 2018, forecast out assuming no change;
2. Current tenure policy and projected timber volume in 2028 using declining trend;
3. Reformed tenure policy with the 20 percent increase in timber volume by 2048; and
4. Reformed tenure policy with the 40 percent increase in timber volume by 2048.

3.2.1 EQUATIONS

The total revenue collected by all departments of the FC (FC_{total}) regarding the harvesting, conveyance, processing and/or exporting of off-reserve timber in each accounting period (t), before the OASL share is disbursed, is the sum of:

(i) revenues accruing from, and therefore, a function of the volume of timber harvested (RV_t) and,

(ii) revenues accruing from fees charged to operators such as loggers, millers and exporters which do not relate to volumes of timber harvested (RF_t).

Hence an estimate of total revenue flowing to the various departments of FC at any accounting period (half-yearly) is given by:

Equation 1

$$FC_{Total_t} = RV_t + RF_t$$

$$RV_t = ST + LMCC + Exp$$

For off reserve, naturally occurring timber, revenues related to volumes harvested (RV_t) include three components as follows;

(i) **The stumpage levy (ST)** is the tax that the FC receives when timber is brought to market. The proposed policy to transfer full ownership of timber resources to landowners and farmers would seek to abolish the stumpage levy. Based on stumpage data obtained from the FC and OASL, the analysis below shows the extent of revenue loss/gain that FC could face if stumpage is abolished in its entirety off-reserve to create the needed incentives for farmers that would eventually translate into volume increases in timber. The stumpage levy is broken down into three classes based on the demand of the timber and different rates are applied to each class: (a) high demand timber, (b) medium demand timber, and (c) low demand timber. This implies that the total stumpage revenue for a given accounting period depends on the proportion of the different classes of timber in the total volume harvested. The accounting is further complicated by the fact that within a given class, different rates are charged for different timber species. Since we could not obtain detailed data on the volume of specific species that were harvested to generate the stumpage figure reported in each period, the average rate for all species in a class was used and that average was applied to the total volume of timber in the class.

(ii) **Log measurement and conveyance certificate (LMCC)** is a tax or levy collected for issuing a certificate of assurance that the true volumes of such products have been taken and captured correctly on the related TIF and LIF. This LMCC is important because it assures legality of the timber operation and determines the stumpage tax which should be invoiced to the rights holder of the timber. It also assures that the vehicle transporting the products is roadworthy, the products are transported at the right time of the day (within 6am-6pm on weekdays or with authorization for transport at weekends), and that the destination of the logs/products is known. It is valid for 72 hours.

(iii) **Export premium (Exp)** is a levy charged on the proportion of the volume of timber that is exported out of Ghana. Its objective is to provide assurance that timber for any particular export parcel has been inspected and met the required quality and quantity specified in the contract. It also indicates that the entity has registered with the TIDD as a timber exporter.

After applying the principal components described above, the revenue collected by FC based on volume of off-reserve timber harvested in each accounting time period (t) is estimated as:

Equation 2

$$RV_t = \left(\sum_{n=1}^{3} St_n\right)_t + LMCC_t + Exp_t$$

Note that to estimate RV_t for a similar volume of timber for plantations off-reserve, $(\sum_{n=1}^{3} St_n)_t = 0$, since stumpage is not charged on off-reserve plantation timber. Equation 2 therefore provides the framework for conducting a comparison to establish revenue losses that FC would face under a new tenure regime that transfers full ownership of trees to farmers and landowners and bring them under the regulatory regime applicable to plantations off-reserve.

RF_t relates to one-off licensing/renewal fees and are not directly related to volume of timber harvested. These include fees for registering a property mark (PM), fees from inspection of farms before harvesting (Insp), and registration fees from exporters and processors (Reg). Hence:

Equation 3

$$RF_t = PM_t + Insp_t + Reg_t$$

Since these revenues are not directly linked to volume of timber harvested, the analysis does not forecast their levels after reform. This is conservative as there may be increases in farm inspections, registration of property marks and other similar revenue when volume of timber harvested increases. The analyses and estimations of total revenue to FC below, therefore, focuses on estimating *RV* (Equation 2) and does not include revenue generated from *RF* (Equation 3). In this regard, findings from the analyses paint a conservative picture; the real figures for total revenue would be higher if one added revenues accruing from *RF*.

To complete the analysis, the timber volume harvested in a half year of 2018 was estimated from the stumpage fees information derived from the FC for that year (FC & OASL, 2018). From this timber volume, the LMCC and export values were conservatively calculated as percentage of total revenues accruing to the FC (see below).

3.2.2 ANALYZING THE VALUE OF STUMPAGE AS A PROPORTION OF TOTAL TIMBER REVENUE UNDER CURRENT TREE TENURE REGIME

The analysis assumes half year stumpage data obtained for 2018, and other data rates related to timber processing and marketing to calculate the total revenue to the FC (FC & OASL, 2018). Table 12 in Annex 2 details the sources of each rate incorporated in the calculations including stumpage rates applied to each timber species, the charges for conveying timber and the charges for processing timber. The authors also obtained data on export levies charged for exporting specific timber species. However, it was not possible to obtain data on proportion of timber exported, so estimates of 20, 30, and 40 percent export proportion were used based on conversations with the TIDD. The proportion of timber exported is a critical variable that contributes to the total revenue the FC receives.

Using the 1.4 million GHC stumpage revenue reported in 2018, the authors calculated the volume of timber harvested and then calculated the fees generated to issue the LMCC and export revenue under three different export scenarios, illustrated in Table 7. The most conservative, 20 percent export estimates, will be used for the calculations of total revenue below.

Article 267(6) of the 1992 Constitution stipulates how "revenue accruing from stool lands" is divided. Under the formulae, the FC retains 50 percent of stumpage fees, and the remaining 50 percent is shared between (i) the traditional council, (ii) the stool, (iii) the district or municipal assembly, and (iv) OASL. Under the proposed reform the FC would continue to receive revenue from issuing LMCC and timber export out of Ghana but would no longer receive revenue from stumpage fees.

In the first half of 2018 the FC received stumpage fees totaling 677,000 GHC. While these stumpage fees can place a financial burden on low-income landowners, these fees make up less than 12 percent of the total revenue to the FC; 11.2, 10.3, and 9.6 percent of total revenue for the corresponding 20, 30, and 40 percent export classes. For the institutions that currently receive the other 50 percent of stumpage fees, their share of total revenue from stumpage fees ranges from one to six percent of total off-reserve timber revenue (Table 8 below). If one factors in total revenue from both off- and on-reserve timber, the loss of stumpage fees would amount to only 4.3 percent and the FC's 50 percent share of this loss amounts to 2.4 percent of the total revenue collected by FC from both on- and off-reserves.

Table 8: Proportion of Total Revenue (Total RV) Made Up by Stumpage Fees

Total Revenues				
Percent Export Quantities	**Stumpage (GHC)**	**LMCC (GHC)**	**Revenue from Exports (GHC)**	**Total RV (GHC)**
20%	1,355,873.20	3,695,147.32	1,003,712.28	6,054,732.80
30%	1,355,873.20	3,695,147.32	1,505,568.42	6,556,588.94
40%	1,355,873.20	3,695,147.32	2,007,424.56	7,058,445.08
Analysis of Stumpage Fees				
Percent Export Quantities	**FC 50% Share of Stumpage (GHC)**	**Total Stumpage as % of Total RV**	**FC Stumpage Share as % of Total RV**	
20%	677,936.60	22.4%	11.2%	
30%	677,936.60	20.7%	10.3%	
40%	677,936.60	19.2%	9.6%	
OASL & Others				
Percent Export Quantities	**OASL Share of Total RV**	**Stool Share of Total RV**	**Traditional Council Share of Total RV**	**District Assembly Share of Total RV**
20%	1.1%	2.5%	2.0%	5.5%
30%	1.0%	2.2%	1.7%	4.8%
40%	1.0%	2.3%	1.9%	5.1%

Section 4 incorporates expectations on tree cover increases the reforms could trigger and provides estimates of resulting increases in total revenue.

4.0 RESULTS

Based on the scenarios outlined in Table 9 the total revenue under the current tenure regime was calculated and compared to the future projected revenue from the low and high scenario. If the current tenure regime is not reformed, timber volumes to be harvested are projected to decline 3.4% annually from the 2018 half-year level of 67,184m³ to a 24,637 m³ half-year by 2048. This translates to a 30% revenue loss, from GHC 5.4 million to an estimated GHC 2.1 million in 30 years (Figure 7).

Based on forecasts of forest cover increases in the next 30 years, the reform is expected to lead to increases in the volume of timber that can be harvested (beginning in 10 years' time) from the 2018 half year volume of 67,184 m³ to a semiannual volume of 80,621 m³ in 30 years under the low scenario. Total revenue to the FC resulting from this increased volume is estimated to be GHC 5.8 million in 30 years' time. This constitutes a 173 percent increase in total revenue from the projected declining timber volume under the current tenure regime.

If the policy reform is supplemented with other incentives, such as tree planting, the high scenario of a 40 percent forest cover increase could be plausible and would generate even more future revenue for the FC. When the high scenario is applied, the volume of timber harvested increases to 94,058 m³, which results in a 202 percent increase in revenue of GHC 6.0 million. These findings include a conservative 20 percent export assumption; see Table 11 in Annex 1 for higher estimates based on 30 and 40 percent export assumptions.

Figure 7: Timber Harvest Projected Under the Current Policy and Proposed Policy Reform

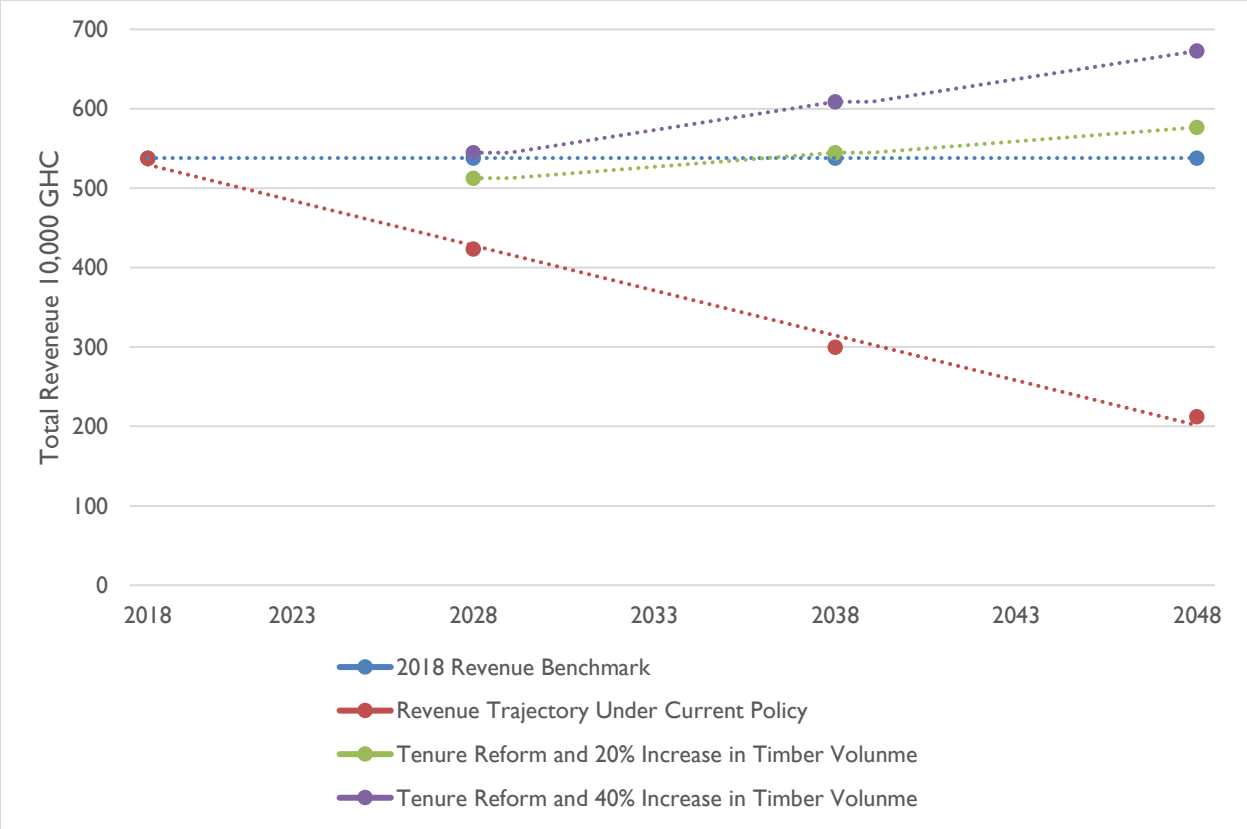


Table 9: Revenue Generated from Four Tree Tenure Scenarios

Tree Tenure Scenario	Tree Vol/Half Year (m^3)	Half Year Stumpage Fees (GHC)	Half Year Log Measurement and Conveyance Certificate (GHC)	Half Year Export Fees (GHC)	Total Half Year Revenue (GHC)	Percent Difference from No Reform Scenario in 10 Years
Current tree tenure regime & 2018 baseline timber volume	*67,184*	*677,936*	*3,695,147*	*1,003,712*	*5,376,796*	*N/A*
Current tree tenure regime & 30-year volume projection	24,638	359,058	1,357,565	408,068	2,124,691	N/A
Reformed tenure and projected 20% timber increase in 30 years	80,621	NA	4,434,155	1,332,853	5,767,008	173%
Reformed tenure and projected 40% timber increase in 30 years	94,058	NA	5,173,190	1,554,998	6,728,188	202%

5.0 CONCLUSION

In the face of declining timber volumes in Ghana as well as the declining percentage of revenue from stumpage fees, it is important that the current policy is reformed to promote regeneration of timber stocks. Implementing a policy reform that devolves tree ownership to farmers and landowners would involve an initial loss of revenue to the FC for the first five to ten years until saplings are mature enough to harvest. However, policy reform would lead to long-term benefits because without intervention the FC is projected to experience a 30 percent loss of revenue. Devolution creates an opportunity for the FC to increase projected future revenue, even while eliminating stumpage fees off-reserve.

A policy that incentivizes landowners to maintain and enhance timber resources on their property is projected to increase the stock of naturally occurring trees off-reserve and has the added environmental benefits of increased canopy cover and carbon removal/storage. Assuming all ecologically viable areas are planted under the new tenure regime, the forest landscape restoration (FLR) tool provided by Bernal et al. (2018) estimates that the benefits could range from 674 million to 787 million tons of CO_2 sequestered in 20 years under the low or high scenarios respectively.[4] This would help Ghana achieve its Paris Agreement targets much more cost effectively than currently contemplated in the updated Nationally Determined Contribution, as the proposed reforms would generate an order of magnitude more emission reductions *and* revenue for government over 30 years compared to the proposed emission reductions from forestry that are anticipated to cost $392 million through 2030. To generate these impacts, the policy reform would ideally be accompanied by publicity campaigns to explain the new law to farmers, and potentially additional support to supply tree seedlings to increase tree planting. This policy shift could also be paired with an expansion of nurseries and extension support to ensure the maximum benefits both to the environment and to the FC. Ghana is already experiencing the impacts of a warming climate and increasing tree cover could provide ecological, hydrological and social benefits (O'Sullivan & Vanamali, 2020; Ministry of Foreign Affairs of the Netherlands, 2018).).

The calculations were conservative and did not consider the full potential of an increase of timber species on cocoa farms that could result from the proposed policy reform. Eighty-three percent of cocoa farms in Ghana do not have adequate shade, so this is 1.8 million ha that could be converted to shaded cocoa which could increase the cocoa yield and provide an additional source of timber stock into the future (Fischer et al., 2020). This paper explored the potential revenue from timber harvesting alone. However, other potential revenue could be ascertained through the carbon market as increased tree cover would yield carbon removals that support Ghana's REDD+ efforts and other avenues of climate finance.

Key assumptions were made in this analysis including the volume of timber exported and the impact that a policy change will have on forest cover within eligible land covers (open forest and cocoa farms). Further data and research are needed to understand the full impact of the proposed policy shift. However, the initial estimates demonstrate that the proposed policy reform would produce gains in revenue that more than offset the FC's initial losses of stumpage fees.

[4] Using the FLR tool available here. The variables used in the calculation include 1,816,091 ha of open forest *not* in the savannah ecoregion as viable to planting, and 20% and 40% increase in tree planting as well as a proportional planting over five years.

ANNEX 1: RESULTS TABLES

Table 10: Total Volume Timber Extracted 1998 – 2015 by Region (On and Off-Reserve). Data from Forestry Commission, 2015

Volume = Volume of timber extracted (m^3) by region on and off-reserve														
	National		Ashanti		Brong Ahafo		Central		Eastern		Volta		Western	
	Volume	Index[5]	Volume	Index	Volume	Index	Volume	Index	Volume	Index	Volume	Index	Volume	Index
1998	1,400,822.3	100	429,580.3	100	267,325.8	100	173,500.4	100	83,785.7	100	1,487.5	100	446,630.1	100
1999	1,469,852.7	105	588,321.3	137	226,464.6	85	123,982.6	71	94,679.7	113	1,487.5	100	434,917.1	97
2000	982,955.4	70	270,908.6	63	217,994.4	82	79,931.5	46	138,101.5	165	2,739.6	184	273,279.8	61
2001	1,245,526.5	89	325,549.3	76	217,882.6	82	128,709.9	74	179,121.8	214	2,320.7	156	391,942.2	88
2002	1,364,392.0	97	291,834.2	68	237,952.7	89	120,667.5	70	216,212.4	258	4,837.8	325	492,887.5	110
2003	1,177,482.3	84	265,937.6	62	203,092.6	76	100,923.4	58	184,127.1	220	3,381.8	227	420,019.6	94
2004	902,232.1	64	201,775.0	47	163,671.2	61	68,972.4	40	139,776.4	167	7,057.3	474	320,979.7	72
2005	934,885.8	67	161,062.6	37	143,307.8	54	73,111.3	42	150,552.6	180	5,233.4	352	401,618.2	90
2006	858,861.1	61	147,171.8	34	140,577.9	53	65,969.2	38	106,420.2	127	5,201.7	350	393,520.4	88
2007	878,498.2	63	148,899.7	35	148,485.1	56	98,927.5	57	114,651.4	137	6,388.3	429	361,146.0	81
2008	898,161.1	64	156,806.6	37	150,626.8	56	97,667.5	56	119,061.6	142	5,094.9	343	368,903.7	83
2009	760,953.0	54	124,077.9	29	113,317.3	42	143,631.5	83	102,867.5	123	7,679.7	516	269,379.1	60
2010	901,154.5	64	182,319.7	42	132,554.5	50	134,911.7	78	109,639.8	131	22,427.2	1508	319,301.6	71
2011	816,420.7	58	160,076.4	37	183,120.6	69	82,126.0	47	94,374.8	113	12,355.7	831	284,367.3	64
2012	864,412.8	62	149,333.2	35	176,852.0	66	66,142.8	38	80,106.5	96	48,483.1	3259	343,495.2	77
2013	1,012,557.0	72	133,134.2	31	286,595.1	107	48,598.8	28	63,714.4	76	20,654.7	1389	459,859.8	103
2014	957,270	68	142,064	33	286,054.9	107	58,497.3	34	55,441	66	20,904.3	1405	394,309	88
2015	778,226	56	99,772	23	159,907.6	60	52,646.9	30	67,306	80	20,752.0	1395	377,841	85

[5] Using 1998 as a base (1998=100), the authors have converted the volume figures into an index which provides the changes in volumes as percentage changes from the 1998 base year.

Table 11: Revenue from Four Reform and Timber Volume Scenarios and 30% and 40% Export Scenarios

Tree Tenure Scenario	Percent Export	Tree Vol/half year (m3)	Stumpage fees (GHC)	LMCC (GHC)	Export fees (GHC)	Total revenue (GHC)	% Difference from No Reform Scenario in 10 Years
Current tree tenure regime half year 2018)	30%	67,184	677,936.60	3,695,147	1,505,568	5,878,652	
Current tree tenure regime & 30-year volume projection		24,638	359,058	1,957,078	797,401	3,113,538	N/A
Reformed tenure and projected 20% timber increase (in 30 years)		80,621		4,434,155	1,999,280	6,433,435	174.8%
Reformed tenure and projected 40% timber increase (in 30 years)		94,058		5,173,190	2,332,497	7,505,687	203.93%
Current tree tenure regime half year 2018)	40%	67,184	677,936.60	3,695,147	2,007,425	6,380,508	
Current tree tenure regime & 30-year volume projection		24,638	359,058	1,957,078	1,063,201	3,379,338	NA
Reformed tenure and projected 20% timber increase (in 30 years)		80,621		4,434,155	2,665,706	7,099,861	175.93%
Reformed tenure and projected 40% timber increase (in 30 years)		94,058		5,173,190	3,109,996	8,283,186	205.25%

ANNEX 2: SUPPLEMENTARY TABLES

Table 12: Variables for Estimating Timber Revenues to FC

Notation	Item	Description	Data Source/Assumptions	FC Division Responsible for the Levy
S_T	Stumpage value	Fees collected by FC based on volume of timber harvested to be shared 50/50 with OASL who then disburses to other stakeholders (stool, traditional authority, district assembly) based on constitutional formula	Actual data obtained from FC and OASL half yearly publication	Forest Services Division (FSD)
	Stumpage class	i. High demand timber ii. Medium demand timber iii. Low demand timber	Proportions assumed based on informed conversation with key players in the timber market (High demand-20%, Medium 50% and low demand -30%)	FSD
	Volume of timber harvested	Total volume of all classes of timber harvested off-reserve in each accounting period	Derived from stumpage value and assumed proportion of stumpage class	
LMCC	Log measurement and conveyance certificate	Certificate (LMCC) of assurance that the true volumes of such products have been taken and captured on correctly	Based on the derived total volume of timber harvested off-reserve and a flat rate per m^3 (currently approximately 55 GHC/m^3)	FSD
Exp.	Value of export levy (GHC)	A levy charged on proportion of timber exported. This is made up of the product of the i. Volume of timber in each stumpage class exported and ii. An export premium for each stumpage class	Proportion exported assumed Data on export premium for timber in each stumpage class obtained from FC (the average of the class was adopted in the calculation)	TIDD
PM	Property mark	Unique registered mark (three letter mark) for timber operators. It gives recognition and identification for authorized timber operators who can fell and transport timber	One time registration fee (currently, 2,000 GHC) and a renewal fee (currently, 200 GHC). Information obtained from FC	FSD
Insp	Inspection fees	Fees collected for administrative services rendered to loggers	A flat rate charged per logging application (currently, 120 GHC/application). Information obtained from FC	FSD

Reg.	Registration of timber exporters/ processors	One off fee charged for registering timber exporter/wood processor	Data not obtained	TIDD

Table 13: Total Volume Timber Extracted 1998 – 2015 by Region (On- and Off-Reserve)

Study	Location	Number of farms	Average shade tree density (# of trees/ha)	Min tree density (# of trees/ha)	Max tree density (# of trees/ha)
Blaser et al., 2018	Ashanti Region	20	59.4	11.1	177.8
Asare et al., 2018	Cocoa growing region	N/A	N/A	2.1	66.7
Asigbaase et al., 2019	Ashanti and Western	86	12-18	N/A	N/A
Abdulai et al., 2020	West Ghana	150	35.5	1	168
Boaitey, 2016	Brong Ahagfo	37 plots	27.3	N/A	N/A
Asante et al., 2017	Cocoa growing region	90 plots	15.6	9.33	22.8
Oututei, 2018	Cocoa growing region	400	6.8	N/A	N/A
Meridia, 2020	Asankrangwa	1032	5.7	N/A	N/A
Weighted average number of shade trees per ha			**10.6**		

Table 14: Shade Tree Density Reported from ECOM within the Western Region of Ghana (54,000 farms total)

Percent of Farms Visited	Range of Number of Trees/ha	Assumed Average Number	Number of Farms
<1%	No shade trees	0	99
41%	1 - 5	2.5	22,099
32%	6 - 10	8	17,248
14%	11 - 15	13	7,546
13%	16 - 16+	NA	7,007

ANNEX 3: SUPPLEMENTARY EQUATIONS

Equation to estimate timber volume from stumpage fees:

$$Tree\ Volume = \left(\frac{Low\ Rate\ x\ Stumpage\ 2018}{Tree\ Volume_{low\ rate}}\right) + \left(\frac{Medium\ Rate\ x\ Stumpage\ 2018}{Tree\ Volume_{medium\ rate}}\right) + \left(\frac{High\ Rate\ x\ Stumpage\ 2018}{Tree\ Volume_{high\ rate}}\right)$$

The following rates were used. The tree volume for each stumpage class and the proportion of each class (represented as rates below) were sourced from conversations with relevant experts at the Timber Industry Development Division (TIDD) in Suyani and Takoradi

Tree Volume $_{low\ rate}$ = 10.48 ghc/m^3

Tree Volume $_{medium\ rate}$ = 28.57 ghc/m^3

Tree Volume $_{low\ rate}$ = 58.32 ghc/m^3

Rate is the proportion of total timber harvested made up of each class low, medium, and high

Low Rate = 0.2

Medium Rate = 0.5

High Rate = 0.3

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U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
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