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Article

Assessment of Socio-Economic and Environmental Impacts of Timber Harvesting in Sierra Leone; Empirical Evidence from a Time Series Data

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Abstract: This study assesses the social, economic, and environmental effects of harvesting timber from the Kambui Hills forest reserve in Sierra Leone, a part of the Gola rain forest, a biodiversity hotspot along the upper Guinea forest zone that stretches through the Manor River Union basin of the Republics of Guinea, Sierra Leone and Liberia. The study area covers an area of 40 kilometers in length and five kilometers in breadth (20,348 hectares of land), with a population of 45,562 residents [1]. A ten-year time series data from 2010 to 2021 is used for this research. The data is processed using EViews 10 statistical software package in a regression analysis. The data set is collected from Food and Agriculture Organization Statistics of the United Nations (FAOSTAT); International Timber Trade Organization (ITTO); and Statistical Office of the European Union (EUROSTAT). A set of specified variables such as primary literacy Level, carbon emissions, inflation, unemployment, Gross Domestic Product (GDP), Exports, and natural resource rent are used to determine the socio-economic and environmental impacts of harvesting timber within the study area. The environmental impacts results from the regression analysis confirmed that R^2 or the coefficient of determination is 0.5734, which shows that 57 % of the dependent variable is significantly explained by the independent variables in the model. Similarly, the economic impact shows an R^2 of 0.8596, which indicates that 86 % of the dependent variable is explained by the independent variables in the model. In the same vein, the social impacts showed an R-square of 0.9667. This is statistically significant as 97 % of the dependent variable is explained by the independent variables in the model. Thus, the regression models confirmed the socio-economic effects of harvesting timber and its environmental impact on the residents of the forest area investigated. This study will conclude with recommendations to the relevant stakeholders in Sierra Leone.

Keywords: timber; harvesting; assessment; impacts; regression analysis

1. Introduction

A major resource advantage on the African continent is the forest hub. Apparently, this could be traced to the socio-economic activities that dominate the continent itself, notably agriculture. Wood products are prominent among the resources harvested, although non-wood products form a substantial quantum of its resources [2,3]. The economic benefits are enormous. In 2017, round wood production alone accounted for 746,340 metric tons in export value from the continent [4,5]. In terms

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of the environmental benefits, services provided by forests are seldomly adequately reflected in forest planning and management decisions [5]. Such services include biodiversity conservation, watershed protection and carbon dioxide sequestration [3]. It also plays a significant role in climate change mitigation due to their ability to sequestrate co2. Similarly, the social benefits of forests across the continent are enormous. It provides beautiful sites for tourism, recreation, spiritual healing, leisure, religious practices and educational purposes through forestry research. [4,6]. However, forest management on the continent is besieged with challenges, and have resulted in adverse consequences in most African countries, especially where timber harvesting and round wood exploitation are prioritized. The removal of forest cover during logging has in some instances resulted in out-right extinction of many important plant and animal species [7–9].

In Sierra Leone, there have been changes in wood-based industries between the eve of the rebel war in 1990 and towards the end of the war in 2002. Specifically, there is a dramatic shift in the study area under review, partly because the KHFR served as a base for the combatants and thus suffered enormously from the war [10]. Notwithstanding the challenges, timber products from the study area have contributed hugely to the socio-economic development of the country generally and the residents of the study area particularly. In 2018, Sierra Leone alone produced and exported 275,000 metric tons of industrial round wood, a total value of 105,699 US$ [11]. Apparently, the forestry sector ranks among one of the highest revenue-generating sectors in the country. Thus, it is inevitable that adverse environmental effects are realized from such socio-economic activities. It is therefore compelling and essential to assess the impact of these activities on the environment. Thus, the need to protect the forests for the present and future generations. In this vein, the indiscriminate logging in the KHFR and uncontrolled felling of trees for fuelwood and other socio-economic purposes should be a concern. Harvesting timber products has both positive and negative effects on the people and environment within the Kambui hills metropolis. The adverse environmental effects are seemingly the consequences of the socio-economic activities through the operations of timber-based industries and other illegal activities.

From this backdrop, this research assesses the gains and losses of harvesting timber products for socio-economic purposes. This assessment is based on quantitative research, wherein a regression model is developed to process a time series of data derived from United Nations (UN) databases.

Hypothesis

The research will test the following hypothesis:

- H01: Environmental impacts of timber harvesting are caused by certain identified factors
- H02: Economic impacts of timber harvesting are caused by certain identified factors.
- H03: Social impacts of timber harvesting are caused by certain identified factors.

2. Materials and Methods

2.1. Methodology

A regression analysis is used for this work. The model is used to measure the marginal socio-economic and environmental impacts of timber harvesting in the research area. A time series secondary data from 2010 to 2021 is used to show the influence of marginal change in the independent variables on the dependent variable. The data was obtained from United Nations data bases and the Statistical Office of the European Union (EUROSTAT). The timeframe for the empirical analysis reflects the most recent trends from 2010 to 2021. The data is ran using statistical software; EViews 10.

2.2. Study Area

The study area is the Kambui Hills Forest Reserve (KHFR) stretching over 20,348 hectare of land space. that was formally declared in 1917 by Charles Lane-Poole, Sierra Leone's first Conservator of Forests and the founder of the country's Forestry Department [2] (Munro and Horst, 2012). The KHFR is endowed with enormous mineral resources and a couple of lakes that are pivotal to the livelihood of the local inhabitants. Forestry work is the main occupation in the study area. The KHFR is in Nongowa chiefdom, Kenema district, Eastern Sierra Leone. It has a population of 45,562 [11]. The

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Kambui Hills are a series of rounded hills stretching from southwest to northeast, covering about 40 kilometres in length and five kilometres in breadth.

2.3. Variable Identification and Model Specifications

For the purpose of this paper, three hypotheses are formulated, each representing the social, economic, and environmental factors. Therefore, carbon emission, GDP and primary enrolment are captured as dependent variables for the three models representing environmental, economic, and social impacts respectively, whereas exports, natural rents, unemployment, labour, inflation, and percentage of GDP are used as explanatory variables in the following models as specified below.

Model 1:

$$ENV_t = \beta_{11}x_{1t} + \beta_{12}x_{2t} + \beta_{13}x_{3t} + \varepsilon_{1t} \quad (1)$$

Where ENV represents environmental factor proxied by carbon emissions as the dependent variable and it is measured in kiloton (kt). The independent variables include X1 = natural rent, X2 = timber exports and X3 = gross domestic product (GDP), where the β's are the coefficients that explain the impact of the independent variables. β11X1t is the natural resource rent, measured in US$. β12X2t is the value of timber exports, measured in US$. β13X3t represents GDP, measured in percentages. ε1t represents error terms.

Model 2:

$$ECO_t = \beta_{21}x_{1t} + \beta_{22}x_{2t} + \beta_{23}x_{3t} + \beta_{24}x_{4t} + \varepsilon_{2t} \quad (2)$$

Where ECO is the economic factor proxied by GDP as the dependent variable, and it is measured in percentages. The independent variables include X1 = natural rent, X2 = exports of timber, X3 = labour productivity and X4 is the rate of inflation. The β's are the coefficients that explain the impact of the independent variables. B21X1t represents natural resource rent, measured in US dollars (US$). B22X2t is the value of timber exports, measured in US dollars (US$). B23X3t stands for labour productivity, measured in US$. β24X4t stands for inflation, measured in percentages. ε1t represents error terms.

Model 3:

$$SOC_t = \beta_{31}x_{1t} + \beta_{32}x_{2t} + \beta_{33}x_{3t} + \beta_{34}x_{4t} + \varepsilon_{3t} \quad (3)$$

Where SOC is the social factor proxied by primary school enrolment as the dependent variable, and it is measured by numerical numbers of primary school enrolment per year.

The independent variables include X1 = natural rent, X2 = timber exports, X3 = labor productivity and X4 is the level of unemployment. The β's are the coefficients that explain the impact of the independent variables. B31X1t represents natural resource rent, measured in US dollars (US$). B32X2t is the value of timber exports, measured in US dollars (US$). B23X3t stands for labour productivity, measured in US$. B34X4t is unemployment, measured in percentages. ε1t represents error terms.

The Materials and Methods should be described with sufficient details to allow others to replicate and build on the published results. Please note that the publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

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3. Results

The results of the regression models as shown in Table 1 below reveals the marginal changes that occurs in the dependent variable as a result of a change in the independent variables across the socio-economic and environmental models within the study area. It presents results from a time series data (2010 – 2021) on the specified dependent and independent variables. See Tables 1 and 2 below for the results and coefficients of determination for the models.

Table 1. Regression analysis results using software EVIEWS 10.

Variable/s	Carbon	GDP	Primary Enrolment
Natural rents	0.0067**	-0.1668**	0.0855
Exports	0.0671	-0.0095**	0.0001**
Gross Domestic Products	0.0266**		
Labor		0.3182**	-0.2019
Inflation		-0.0273	
Unemployment			6.0770*
Constant	-0.0596	15.6823**	-13.6689

Notes: The asterisks (*, **, ***) denote statistical significance at 0.1, 0.05, and 0.01 levels, respectively; using observations 2010-2021 (T = 12).

Table 2. Coefficients of determination for the models.

Coefficients/Variables	Environmental impacts	Economic impacts	Social impacts
Prob(F-statistic)	0.0061	0.0042	0.0000
R-squared	0.5734	0.8596	0.9667
Adj. R-squared	0.4134	0.7794	0.9477
Normality	0.6528	0.0421	0.6583
Heteroscedasticity	3.6022	0.8963	10.0355
Serial Correlation	2.6383	4.4074	1.2576
Functional Form	0.0124	0.7297	0.1641
Cumulative sum	Stable	Stable	Stable
Cumulative sum^2	Stable	Stable	Stable

3.1. The Environmental Impacts

The dependent variable for environmental impact is proxied by carbon emission, and it is regressed to ascertain the influence of each of the following independent variables: Natural Rent, Exports, and GDP. It further indicates that the amount of carbon emitted in the environment is influenced by the amount of natural rent royalties received for a given forest space used for timber harvesting, the percentage amount contributed to the GDP, and the exports value of timber harvested. To determine a statistically significant relationship between carbon emission and natural rent, the OLS estimation test was ran and the result suggests a p-value of 0.05.

The results above suggest that the relationship between the variables is statistically significant. It supports the hypothesis that a change in natural rents will influence the amount of carbon emitted into the environment. To also determine a statistically significant relationship between carbon emission and GDP from the OLS estimation test, a p-value of 0.05 was obtained, which also separately supports the hypothesis that a change in the GDP will influence the amount of carbon emitted into the environment. There is also a significant relationship between the export as an independent variable and carbon emission, where a 0.0671 increase in export will lead to a unit change in carbon emission. Thus, the result confirms the first hypothesis that carbon emission impacting the environment is influenced by the independent variables in the model. The model can be illustrated below.

 doi:10.20944/preprints202410.1605.v1

Model 1: Co2 Emission = Natural rent + Export + GDP

y= 0.0067** + 0.0671 + 0.0266**

where y is the dependent variable, regressed by the independent variables of Natural rents, exports and GDP, respectively.

Statistical test of significance conducted for variables used to determine the environmental impacts shows an R^2 of 0.5734 with an adjusted R2 0.4134. This shows that the independent variables in the model significantly explain 57 % of the dependent variable. The Normality test also determined that the data used in the research have a normal distribution. It shows 0.6528 (65 %) of normal distribution level. The Heteroscedasticity test measured at 3.6022 showed non-volatility in both dependent and independent variables, given a constant level of -0.0596. Furthermore, serial correlation shows 2.6383 which indicates that the observations in this model are serially correlated. A functional form of 0.0124 also signifies a relevant relationship between the dependent and independent variables. The Durbin-Watson test reveals a positive autocorrelation between the variables as well. The Cumulative sum and sum of square tests was done to determine parameter stability. The tests show stability in the model. All other classical statistical tests and assumptions showed a satisfactory level of significance.

3.2. The Economic Impacts

The dependent variable for economic impact is proxied by GDP, and it is regressed to ascertain the influence of each of the following independent variables: Natural Rents, Exports, labor participation and inflation. It further indicates that the contribution to GDP from timber harvesting is influenced by the value of natural rent royalties received for a given forest space used for timber harvesting, the labor input for a certain quantity of timber harvested, and the inflation of timber products over a given period. To determine a statistically significant relationship between GDP and natural rent, the OLS estimation test reveals a p-value of 0.05, suggesting that the relationship between the variables is statistically significant. Thus, it supports the hypothesis that a change in natural rents will influence the amount contributed to GDP in the economy. To also determine a statistically significant relationship between GDP and export from the OLS estimation test, a p-value of 0.05 was obtained which also separately supports the hypothesis that a change in the timber export value will influence the amount contributed to the economy's GDP.

There is also a significant relationship between labour input as an independent variable and GDP, where a unit change will lead to a change in contribution to GDP. However, the result shows a negative relationship between inflation and GDP, although the F-statistics confirms a significant relationship between the two variables. Thus, the result suggests that the independent variables separately influence the dependent variable and confirms the second hypothesis that GDP is influenced by natural rents, exports, labour, and inflation, separately or collectively. The model is illustrated below.

Model 2: GDP = Natural Rent + Export + Labour + Inflation

y = -0.1668** + -0.0095** + 0.3182** + -0.0273

where y is the dependent variable, regressed by the independent variables of Natural rents, export, labour and inflation, respectively.

The statistical test of significance for the variables used to determine the economic impact revealed an R^2 of 0.8596 with an adjusted R2 of 0.7794. This shows that the independent variables in the model significantly explain 86 % of the dependent variable. The Normality test also determined that the data used in the research have a normal distribution. It shows 0.0421 of the normal distribution level. The Heteroscedasticity test measured at 0.8963 which shows a non-volatility in both dependent and independent variables, given a constant level of 15.6823**.

Furthermore, serial correlation shows 4.4074 and thus indicates that the observations in this model are serially correlated. A functional form of 0.7297 also signifies a relevant relationship

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between the dependent and independent variables. The Durbin-Watson test reveals a positive autocorrelation between the variables as well. The Cumulative sum and sum of square tests were done to determine parameter stability. The tests show stability in the model. All other classical statistical tests and assumptions were satisfied.

3.3. The Social Impacts

The dependent variable for social impact is proxied by primary enrolment, and it is regressed to ascertain the influence of each of the following independent variables: Natural Rents, Exports, labor participation and unemployment. It further indicates that students' primary enrolment is influenced by the value of natural rent royalties received for a given forest space used for timber harvesting, the labor input for a certain quantity of timber harvested, the export value of timber harvested and the unemployment level in the study area over a given period.

To determine a statistically significant relationship between primary enrolment and natural rent, the OLS estimation test reveals a positive relationship between the variables, thereby suggesting that it supports the hypothesis that a change in natural rents will influence the number of students enrolled in primary schools in the study area. To also determine a statistically significant relationship between primary enrolment and export from the OLS estimation test, a p-value of 0.05 was obtained, which also supports the hypothesis that a change in the timber export value will influence primary enrolment in the community. Although the result showed a negative relationship between labor input and primary enrolment, it does confirm from the prob (F-stat) that there is a high significant relationship between the independent variables and primary enrolment, where a unit change will lead to a change in the dependent variable as well. Similarly, the OLS test also reveals a positive relationship between unemployment and primary enrolment with a p-value of 0.1, which supports the hypothesis that a change in unemployment will result to a change in primary enrolment. These results suggest that the independent variables, separately and collectively, influence the dependent variable. This further confirms the third hypothesis that primary enrolment in the community is influenced by natural rents, exports, labor input and unemployment. The model can be illustrated below as follows.

Model 3: Primary enrolment = Natural Rent + Export + Labor + unemployment.

$y = 0.0855 + 0.0001^{**} + -0.2019 + 6.0770^{*}$

where y is the dependent variable, regressed by the independent variables of Natural rents, export, labor and unemployment, respectively.

The test of statistical significance for the social impact model reveals an R^2 of 0.9667 with an adjusted R2 of 0.9477. This shows that the independent variables in the model significantly explain 97 % of the dependent variable. The Normality test also determined that the data used in the research have a normal distribution. It shows 0.6583 of (65%) normal distribution level. The Heteroscedasticity test measured at 1.0355 showed non-volatility in both dependent and independent variables, given a constant level of -13.6689.

Furthermore, serial correlation shows 1.2576, thus indicating that the observations in this model are serially correlated. A functional form of 0.1641 also signifies a relevant algebraic relationship between the dependent and independent variables. The Durbin-Watson test reveals a positive autocorrelation between the variables as well. The Cumulative sum and sum of square tests were done to determine parameter stability. The tests show stability in the model. All other classical statistical tests and assumptions were satisfied.

 doi:10.20944/preprints202410.1605.v1

4. Discussion

With regards to the regression models, this work investigates the significant influence of the variables such as: natural rents/royalty, value of timber exports, inflation of timber products, unemployment, and percentage contribution to GDP. It shows an empirical margin of influence of the independent variables on the dependent variable, collectively or separately. The research hypothesis was supported by the results from the regression analysis, as expressed in Table 3 below.

Table 3. Hypothesis results.

Hypothesis	Prob (F-stat)	R^2	Adj. R^2	Serial correl.	Heteroscedasticity	Normality test	Results
H_1	0.0061	0.5734	0.4134	2.6383	3.6022	0.6528	Supported
H_2	0.0042	0.8596	0.7794	4.4074	0.8963	0.042	Supported
H_3	0.0000	0.9667	0.9477	1.2576	10.0355	0.6583	Supported

The first hypothesis represents the environmental impacts of timber harvesting within the study area. The F. statistics of 0.0061 in the model suggests that all the explanatory variables jointly influence the dependent variable in the model. The R2 and adjusted R2 are 0.5734 and 0.4134 respectively. The estimated results show that the Adjusted R2 accounted for the variability in the response variable in the model, while the R2 shows that 57% of the independent variables do explain the dependent variable, thus rendering the model valid. Assuming everything remains the same, the heteroscedasticity indicates a non-volatility in the model while the serial correlation validates the normal correlation among the variables. The normality test also confirms a normal distribution of the variables in the model.

Thus, from the result obtained, it can be confirmed that the independent variables used to explain the dependent variables are significant and the model is stable, suggesting therefore that it supports the hypothesis that environmental impact (carbon emission) is a result of certain factors like natural resource rents, export value of timber products and the total value contribution to national GDP. According to the result obtained, these independent variables, separately or collectively, significantly influence the dependent variable. This result is supported by findings from Jing Luo et al. [12], who concluded that harvesting a wood product can play an important role in reducing carbon emissions while managing healthy forests. It is further supported by the annual report of the United States Department of Agriculture [13], which suggested that the best way to explain the effects of forest management on the atmosphere is to consider what the atmosphere appreciates regarding carbon entering or leaving. Other works that supported this conclusion include [14–20], all concluded that there is a significant relationship between carbon emission and the independent variables of natural rents, exports, and GDP.

The second hypothesis represents the economic impacts emanating from timber harvesting within the study area. The F. statistics of 0.0042 in the model suggests that all the explanatories.

Variables jointly influence the dependent variable in the model. The R2 and adjusted R2 are 0.8596 and 0.7794 respectively. The estimated results show that the Adjusted R2 of 78% accounted for the variability in the response variable in the model, while the R2 shows that 86% of the independent variables do explain the dependent variable, thus rendering the model valid. Assuming everything remains the same, the heteroscedasticity indicates a non-volatility in the model while the serial correlation validates the normal correlation among the variables.

The normality test also confirms a normal distribution of the variables in the model. Thus, from the result obtained, it can be confirmed that the independent variables used to explain the dependent variables are significant and the model is stable, suggesting, therefore that it supports the null hypothesis that economic impact (GDP) is a result of certain factors like natural resource rents, the export value of timber products, labor input and inflation in the prices of timber products. According to the result obtained, there was a negative relationship between some of the independent and dependent variables. However, with a p-value of 0.05 for almost all the intended variables, it can be confirmed that there is a significant statistical relationship between the variables, enough to

 doi:10.20944/preprints202410.1605.v1

separately or collectively, explain the significant influence on the dependent variable separately or collectively. This result is supported by findings from other literature [21–24], who all concluded that there is a compelling relationship between the GDP of a country and natural resource rents, export value, labor and inflation in timber harvesting.

The third hypothesis represents the social impacts emanating from timber harvesting within the study area. The F. statistics of 0.0000 in the model suggests that all the explanatories.

Variables jointly influence the dependent variable in the model. The R2 and adjusted R2 are 0.9667 and 0.9477 respectively. The estimated results show that the Adjusted R2 of 95% accounted for the variability in the response variable in the model, while the R2 shows that 97% of the independent variables does explain the dependent variable, thus rendering the model valid. Ceteris paribus, the heteroscedasticity indicates a non-volatility in the model while the serial correlation validates a normal correlation among the variables. The normality test also confirms a normal distribution of the variables in the model. Thus, from the result obtained, it can be confirmed that the independent variables used to explain the dependent variables are significant and the model is stable, suggesting, therefore that it supports the null hypothesis that social impact (Primary school enrolment) is a result of certain factors like natural resource rents, export value of timber products, labour input and unemployment within the study area.

According to the result obtained, one of the independent variables shows a negative relationship with the dependent variable. However, with a p-value of 0.05 and 0.01 for two of the other independent variables, it can be confirmed that there is a significant statistical relationship between the variables, enough to separately or collectively explain the significant influence on the dependent variable. Findings from other literature support this result [25–31], who all opined that there is a significant relationship between education and such variables like natural resource rents, exports, labour, and unemployment in timber harvesting.

Thus, the paper satisfied the hypothesis in identifying the factors that influenced the socio-economic and environmental impacts from timber harvesting. The social impacts proxied by primary enrollment as the dependent variable, confirmed that it is influenced by natural rent, export, labour, and unemployment as the independent variables. Similarly, the model confirmed that the independent variables; natural rent, export, labour, and inflation does influence GDP, which is proxied as the dependent variable representing economic impact. In the same vein, the result confirmed that independent variables such as natural rent, export, and GDP influenced carbon emission, which is proxied as the dependent variable representing environmental impact.

5. Conclusions

This section is not mandatory but can be added to the manuscript if the discussion is unusually long or complex.

This paper assesses the social, economic, and environmental effects of harvesting timber from the Kambui Hills Forest Reserve, Kenema district in Sierra Leone. The methodology is an empirical investigation of a time series data set (2010-2021), using an OLS through regression models. The data is obtained from United Nations data bases to specifically identify timber harvesting impacts, using variables proxied for the socio-economic and environmental impacts.

Furthermore, findings from this work confirms that timber harvesting affects the socio-economic and the environmental well-being of the respondents in the study area in many ways than one. These effects have a direct or indirect consequence on global warming and climate change as they lead to increased GHG emissions. Although the residents in the study area harvest these resources for immediate survival from poverty and hunger; the future will only reinforce the perpetual scourge of hardship.

The paper concludes that timber harvesting is a financially popular socio-economic activity for the society, but it is also devastating for the environment if sustainable forest management principles are ignored. It is evident from the results obtained that harvesting timber products unsustainably is a self-destructive route for any country. This conclusion aligns with the findings of Kamara and Su [32] and Uzu et al. [33], both of whom opined that if timber harvesting is left uncontrolled, it will

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eventually lead to factors that will increase greenhouse gas (GHG) emissions. From the foregoing conclusion, it is important to implement the following recommendations:

Policy Recommendations

There should be premium on the role of sustainable impact assessment in the face of inevitable socio-economic activities within the KHFR in Sierra Leone. This is more relevant now than ever and the need for an effective data collection, retainment and preservation at local, national, and global level is even more crucial. This can help Government officials, forest managers and other stakeholders to make informed decisions on sustainable forest management principles in going forward.

The Sierra Leone government should consider investing in training forest guards in accurate data collection and preservation standards. Developing avenues to make this information more readily available at the community level could provide a strong bargaining position for these communities in their dealings with other actors. This will also mitigate the chances of inconsistent data obtained from international organizations.

The development of alternative livelihoods is also crucial to reduce reliance on forestry resources as the main income generating source. The need for actual income earning options that is well suited to the local context should be provided by stakeholders. Some examples have already emerged in some of the communities and could be spread to others. For instance, one community could be involved in providing food for the school feeding program and another community engaged in honey production, or other agro-based food processing activities as part of a diversification process. The improvement of community infrastructure, notably schools and health clinics, is also vital for the long-term improvement of community livelihoods.

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