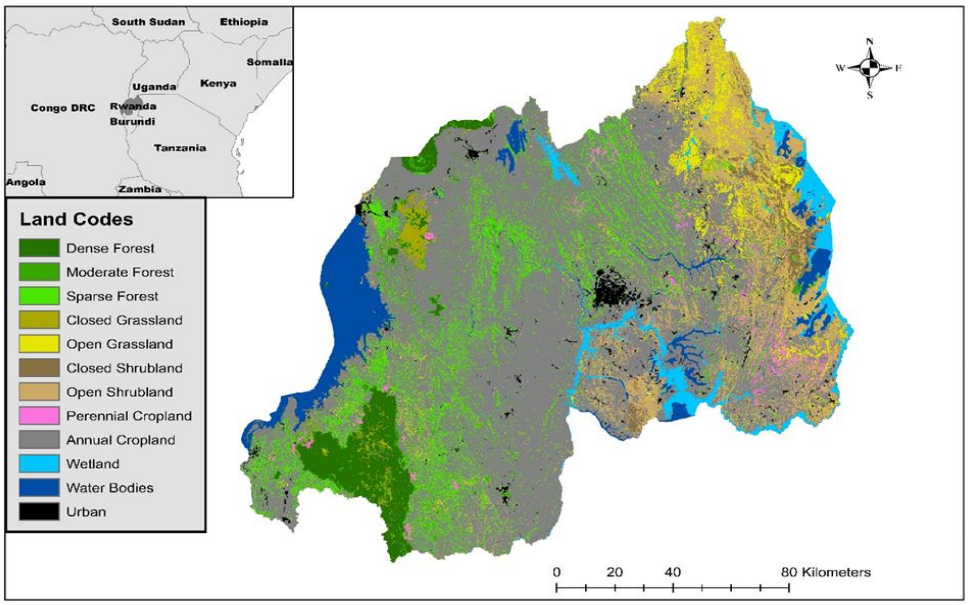

Rwanda 2015 Land Cover (RCMRD, 2017).

Policy Brief: Achieving Green Growth through Terrestrial Natural Capital Restoration in Rwanda.

Executive Summary.

Rwanda, a growing country in Sub-Saharan Africa, has suffered significant damage to its environment over the last few decades, and has begun the process of using policy to reverse this trend. Though aggressive strategies have achieved some success, growing social, environmental, and economic constraints have made increasing the effectiveness of these strategies critical.

To this end, this policy brief summarizes the use of the innovative integrated economic and environmental model (IEEM) coupled with land use land cover (LULC), and ecosystem service models (IEEM+ESM) to understand how various policy interventions can affect economic, poverty amelioration, and environmental outcomes. We constructed a base scenario using the "business as usual" approach, then compared it to five other approaches that prioritize various policy interventions, including agroforestry expansion on farm-lands, cropland consolidation, fertilizer and irrigation improvements in agriculture, and combined approaches.

Through integrated and innovative methods, we are able to understand how land degradation due to erosion can affect not only economic indicators such as GDP, poverty reduction, genuine savings, and unemployment, but also land assets, land use changes, ecosystem service supply, and terrestrial natural capital. Results suggest that investments in productive infrastructure for fruit plantations may not be sufficient to reduce imports additional measures such as gradually expanded and increase food and nutritional security. As a result, irrigated agriculture, land consolidation to increase productivity, and increased fertilizer application following an integrated approach for land asset management and conservation can enhance economic well-being, help counter environmental degradation, and increase ecosystem services supply.

1. Introduction

The last five decades have seen humans totally transform ecosystems, resulting in substantial net gains to their well-being and economic development, but at the cost of degrading many ecosystem services (Bagstad et al., 2020; Rukundo et al., 2018). Agriculture is one of the greatest contributors to land use/landcover change (Brown et al., 2017; Rukundo et al., 2018). In Sub-Saharan Africa (SSA), land degradation resulting from agriculture is more pronounced due to pressure driven by population growth (Bagstad et al., 2020; Rukundo et al., 2018) By the year 2030, 540 million people will depend on land for income and food security in Sub-Saharan Africa (SSA) alone (Buckingham et al., 2020). The cost of land degradation is estimated at 3% of SSA's annual agricultural GDP (Uwimana et al., 2018). This estimated deficit has led to political strategizing in support for green development policies. Rwanda is at crossroads in terms of the socio-economic pressure on land resources because of challenges such as forced resettlement, recent conflicts, high population density, land terrain, and climatic factors that result in land degradation (Rukundo et al., 2018). Currently, 40.5% of Rwanda's arable land is under threat of erosion and requires soil maintenance (Rukundo et al., 2018).

The main task at hand is to increase land use and tree cover as part of economic development and poverty reduction strategies (Buckingham et al., 2020; Verdone and Seidi, 2016). Land degradation continues to be is a major concern in Rwanda, with field-reported soil losses ranging from 35 to 246 tons ha/yr (Olson and Berry, 2004). The loss of soil has reduced the capacity to feed 40,0000 Rwandans annually (Uwimana et al., 2018; Verdone and Seidl, 2016). This decline can be attributed to increasing rural population and land fragmentation that has put additional pressure on subsistence farming households (Olson and Berry, 2004; Clay and Lewis, 1990). Various demographic, economic and environmental trends explain Rwanda's environmental degradation, and highlight the necessity of agroforestry restoration investments. If implemented these initiatives could be critical in the process of regaining ecological functionality and in helping Rwanda live up to its commitments of achieving a countrywide reversal of natural resource degradation.

Currently, 70% of Rwanda's active population is employed in agricultural production (IFAD, 2019) and approximately, 96% of rural households are dependent on agriculture for their livelihoods (NISR, 2018). Factors that impacts the availability of natural resources will have direct effect on the livelihood of the citizenry. Furthermore, the reliance on agriculture and natural resources has increased pressure on the environment. In addition to the population changes, Rwanda's economy has shown considerable change over the last few decades, with an increase of GDP at an average of 7.9% per year since 2000 (Government of Rwanda, 2019). These changes in economic performance are invariably linked to greater demand for natural resources, which is further exacerbated by growing population. This phenomenon has led to significant changes in land use and land cover patterns, which have been accompanied by reductions in biomass, biodiversity, and ecosystem services (Bagstad et al., 2019; Banerjee et al. 2020).

2.0 Methods

Our study explores management and policy prescriptions to combat land degradation, restore ecosystems, and create co-benefits such as sustainable agriculture, food security, improved human health, inclusive economic growth, improved employment, and climate change mitigation. Our approach develops an innovative methodology for development planning by integrating economic, environmental, and ecosystem service models to inform decisions on the allocation of scarce resources to achieve complex development goals. Specifically, we apply the Integrated Economic-Environmental Modeling (IEEM) Platform, linked with ecosystem services modeling (IEEM+ESM), an innovative decision-making framework for exploring complex public policy goals and analyzing synergies and trade-offs between alternative policy portfolios (Banerjee, Cicowiez et al. 2019).

2.1 Land Use Land Cover Change Model

The Land Use Land Cover (LULC) Change Model provides the linkage between IEEM and ESM. It was used to spatially allocate LULC change numerically estimated by IEEM for each scenario and time step across the country. The LULC Change Model was developed using the Conversion of Land Use and its Effects (CLUE) model framework, a flexible and spatially explicit land use and land cover modeling framework (Verburg and Overmars, 2009).

2.2 Ecosystem Service Modeling

We use the Integrated Valuation of Ecosystem Services Tradeoffs (InVEST) modeling software (Sharp, Tallis et al. 2018) to quantify carbon storage, nutrient regulation, and annual and seasonal water yield in Rwanda. We ran this model for 2015, and for 5-year increments for BASE and the other five scenarios. We used the erosion and overland sediment retention to provide feedback to the IEEM model in Rwanda between 2015 to 2035 at five-year intervals.

2.3 Ecosystem Services Supply Feedback in IEEM

Erosion and erosion mitigation services occur in the baseline business as usual case and in the future scenarios. We establish severe erosion (greater than 11 tons/ha/yr) in the baseline by identifying the number of pixels exhibiting severe erosion. We implement this agricultural productivity shock in IEEM for the year 2020 and generate new results for the period of 2020 to 2035 for economic and natural capital impact indicators and demand for different land use. We ran the LULC change model and ES model for the 2015 to 2035 period and estimate changes in ES supply and the resulting changes in agricultural productivity.

Policy scenarios were implemented in IEEM, including interventions to expand irrigated agriculture and increase fertilizer application, land consolidation, and horticultural trees plantations on farmland as part of the agroforestry strategy. Using the first time-period of 2015 to 2020, we generated estimates for impacts on the economy, natural capital, and demand for land. We spatially allocated the demand for land for each scenario with the Conservation of Land Use and its Effects (CLUE) based LULC change model to generate new LULC maps for the year subsequent 5 years. The policy scenarios were as follows.

Scenario 1: Only agroforestry expands with fixed forestland (AGROFOR). This scenario assumes an increase in agroforestry area to a total of 1,110,476 hectares by 2030.

Scenario 2: Cropland consolidation (LANDCON). We implement this scenario of cropland consolidation such that both food crops area and export crops yield increase. Crop productivity increases by 30% in newly consolidated cropland throughout 2019-2024 (IFAD, 2019).

Scenario 3: Both agroforestry and cropland consolidation (COMBI12). This is the combined scenario comprised of Scenario 1 and 2. Here, agroforestry expands to 1,110,476 hectares by 2050, and the cropland consolidates from the current 635,603 hectares to 980,000 hectares by 2024. The interplay of agroforest program along with cropland cover is allowed and can come from conversion of arable land and open grasslands.

Scenario 4: Agriculture-improvement in fertilization and irrigation (FERTIRRIG). This scenario involves increasing the fertilizer use by 134% (75 kg/ha) in tandem with a modest increase in irrigable area by 0.6%/year through 2035. The plan also estimated that the cost of integrated input use including fertilizers is about $450 million, and that of use of improved irrigation methods is about $450 million over a period of 2018-2024.

Scenario 5: Comprehensive implementation of policies (COMBI). This scenario implements Scenarios 3 and 4 together and examines the interactions of agroforestry and improvements in agricultural productivity in the context of economic development within a sustainable environment.

3. Results

3.1 Economic Impacts

The economic implications of the five scenarios are provided in two ways in comparison to the baseline results. In the first way, we compare the first and last year of simulation with respect to the base year to assess the overall change in each indicator of economic performance that results from implementing that scenario. In this brief, we also make use of various indicators of economic performance to measure the economic impact of implementing different scenarios. This helps us better determine in which specific aspect a scenario performs well and in which ones it performs poorly (Table 1)

Table 1. Real Macroeconomic Indicators in 2035 with respect to Base (2019 US$ Million, Difference with respect to Base).

Macroeconomic Indicator	AGRO FOR	LANDC ON	COMBI 12	FERTIR RIG	COMB I
Absorption	4	1,163	1,175	315	1,472
Exports	-5	105	100	20	119
Imports	-8	91	82	17	99
GDP at Market Price	7	1,178	1,193	317	1,493
GDP at Factor Cost	-40	1,078	1,032	292	1,310
Net Indirect Tax	-4	63	61	16	76

Source: Integrated Economic-Environmental Modeling and Ecosystem Services Modeling results for Scenarios.

The overall trend from table 1 indicates that the LANDCON and COMBI12 scenarios had a greater impact across the microeconomic indicators as compared to other scenarios. In Figure 1 below, specifically depicts how the model estimated year to year change in real GDP factor cost for the most salient macro-economic indicator.

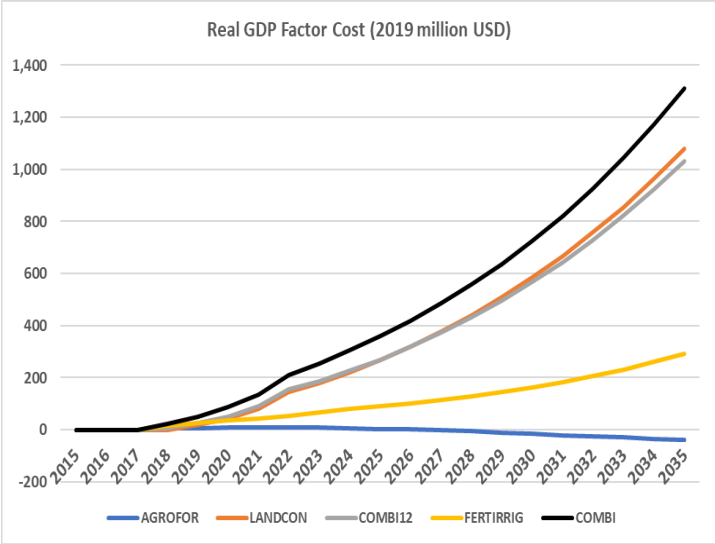

Figure 1. Model estimated change in Real GDP At Factor Cost Compared to the Base Case.

The AGROFOR scenario performs poorly compared to all the other scenarios, and the real private consumption goes below the baseline by 2035. When we consider this standalone AGRIFOR policy, it showed negligible overall impact mainly because it did not boost the economic output. Unlike agriculture, agroforestry does not yield benefits unless harvested for its economic value.
Overall, the LANDCON scenario showed dominance relative to other individual scenarios with the highest measure of GDP (0.18% per annum). Increases in agricultural production increase the disposable income of agricultural households, further enhancing their aggregate consumption.

This is a key revelation that Rwanda's strategic plan for agricultural transformation will advance agricultural production as well as boosting the economy. The change in real GDP at factor cost, which is measured based on the cost of production without accounting for indirect taxes, showed exponential growth in the overall COMBI scenario; most of this GDP growth came from LANDCON, followed by FERTIRRIG scenarios. Given that the agriculture sector contributes to nearly one-third of Rwanda's GDP, the LANDCON and FERTIRRIG scenarios increase agricultural activities and production leading to growth in real GDP. Though the AGROFOR scenario does not necessarily contribute towards real GDP growth in the long run, it is an important sector that would also contribute towards sustainable economic growth in the region if designed to yield economic returns.

3.2 Land Cover Impacts

The results in figure 2 show that the land assets change across scenarios largely due shifts in livestock and agriculture (fruit crops on farmlands as part of agroforestry investing and perennial crops in lieu of non-perennial crops.

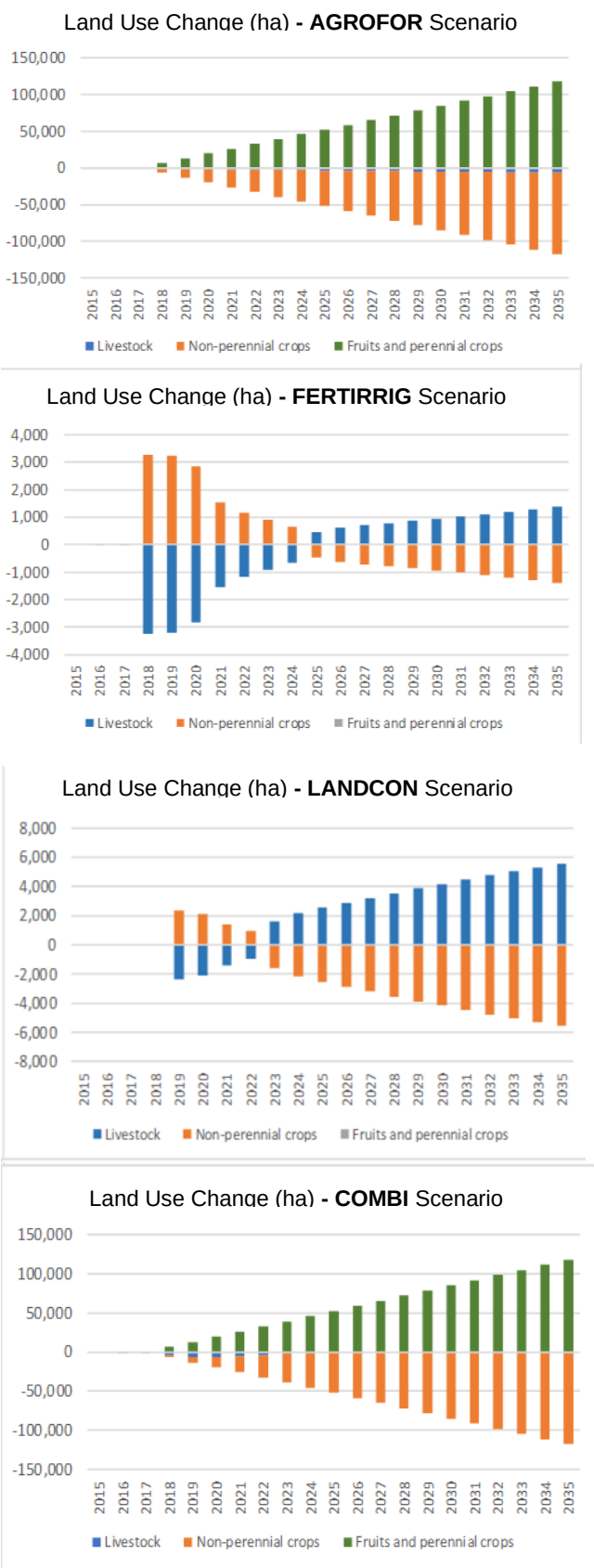

Figure 2: Land use Change (hectares) with respect to Base across Scenarios

The AGROFOR scenario shows that by 2035, the land under fruits and perennial crops increases by 117,580 hectares; most (94%) of this comes from conversion of non-perennial cropland, and 6% comes from the conversion of livestock (pasture and grassland). In the LANDCON scenario, the model predicts a relatively smaller magnitude of land use change, with only 5,567 hectares of pasture and grassland expansion coming from conversion of land under fruits and perennial crops. The COMB12 scenario was dominated by the AGROFOR scenario.

3.3 Ecosystem services Impacts

InVEST based Ecosystem service models enabled the quantification of changes in ecosystem services for all scenarios until 2035 and compared the base scenario to the other five scenarios at a national scale.

Table 2: Reports changes in ecosystem services as the percent difference from the BASE in 2035.

	AGROFOR	LANDCON	COMBI12	FERTIRRIG	COMBI
Carbon storage	11.75%	0.10%	11.81%	0.15%	11.77%
Annual water yield	15.96%	0.01%	15.93%	-0.01%	15.92%
Quick Flow	-24.07%	-0.12%	-24.24%	-0.13%	-24.29%
Local recharge	19.23%	0.01%	19.33%	0.02%	19.39%
Sediment export	-40.48%	-0.47%	-40.60%	-0.50%	-40.51%
Nitrogen export	-75.05%	-0.32%	-74.36%	112.51%	-60.74%
Phosphorus export	-72.27%	-0.33%	-73.14%	114.78%	-59.22%

Carbon storage increased across all five scenarios, depicting improved ecosystem services. Annual water yield increased in four scenarios, excepting a marginal decrease showcased in the FERTIRRIG scenario. Increases in annual water yield indicate less evapotranspiration and more runoff, but the implications are not straightforward (Bagstad et al., 2019). Fruit tree plantation activity represented by AGROFOR, COMBI12, and COMBI scenarios reflect substantial ES change compared to LANDCON and COMBI12 scenarios. The AGROFOR, COMBI12, and COMBI scenarios also led to larger reductions in sediment export, depicting erosion control caused largely due to expanded tree plantations on arable land and grasslands. LANDCON and FERTIRRIG scenarios also represent a slight decrease in erosion, though the decrease is much lower than the one could observe in the base case without policy interventions. Nitrogen and phosphorus export decreased substantially in AGROFOR, COMBI12, and COMBI scenarios, signifying larger ES improvements.

The FERTIRRIG scenario, on the other hand, showed substantial nutrient export, largely expected due to increased fertilizer application and irrigation.

While both substantially increased the application of nutrients to croplands, tree plantation in the COMBI scenarios was enough to retain most of nitrogen and phosphorus, signifying improvement in land assets and associated ES. Differences between LANDCON and FERTIRRIG scenarios are notable for almost stable water yield, a decrease in sediment export and quick flow, and smaller increases in carbon storage and local recharge services. The difference is pronounced in terms of nutrient exports, where FERTIRRIG leads to a substantial increase in nitrogen and phosphorus as compared to a slight decrease in the LANDCON scenario.

Summary and Policy Recommendations

The IEEM model showed that the AGROFOR scenario implemented alone had negligible economic impacts, even though policy induced land use change was significant in impacting non-perennial cropland.

Economic impacts under the LANDCON scenario were positive and greater compared to other two individual scenarios. Land consolidation coupled with boosting agricultural productivity provided greater economic benefits in terms of GDP growth, absorption, increase in private consumption, reduction in unemployment, and improvement in wages. The LANDCON scenario also showed the potential to lift more Rwandans above the national poverty line. Similar trends on economic impacts were observed under FERTIRRIG scenario, but with lesser magnitude. Increase in fertilization and irrigation showed gradual increase in GDP and drop in headcount ratio under poverty.

The COMBI scenario indicated an outcome that would provide stronger positive economic impacts when all these policies are implemented simultaneously. This is because the productivity increase on the existing and new cropland help boost overall crop production, resulting in lower crop prices, thereby improving private consumption as well as the export potential of the country. The combined scenario showed drastic reduction in poverty headcount ratio, particularly in the immediate years of policy implementation, which is attributed to intensity of economic activities during the policy phase when nearly 5 million people were below the poverty line. By 2035, the COMBI scenario resulted in less than 1.6 million Rwandans in poverty.

The land cover change in the IEEM model revealed a drastic expansion of agroforestry under AGROFOR scenario. Due to interaction of alternate land-use activities, pressure on livestock-based pasture and grassland decreases under the COMBI scenario. Under LANDCON and FERTIRRIG scenarios, the net year to year change in non-perennial cropland, though small, was positive throughout the policy implementation stage, but in the long run (post-2025), the trend reversed towards expansion in grassland and pasture due to livestock activities. However, when all the three individual scenarios were implemented together, the COMBI case showed an overall gradual expansion in fruits and perennial cropland with the reduction in non-perennial cropland, but did not negatively affect grassland and pastureland. This means that boosting agricultural productivity would significantly help in reducing the pressure on cropland to meet the demand for crop production, which further helps in agroforestry expansion and acreage consolidation. This reveals a significant need for designing and implementing the policies on agriculture, forestry, and land use change in tandem, as they interact with each other to provide the best possible socio-economic and environmental benefits.

Therefore, given the results of our models, we recommend that the government take measures to begin implementing the COMBI scenario. This scenario has few negative impacts, and shows strong improvements in socioeconomic and environmental outcomes. Given the complexity and economic demands of such a broad scenario, we would also recommend implementing LANDCON and FERTIRRIG scenarios if COMBI is economically or politically infeasible; both of these scenarios provide economic benefits and poverty amelioration, though LANDCON tended to have the better impacts of the two. These policies have shown positive results in our modeling, and may represent the best path Rwanda has to overcoming their current challenges. However, it should be noted that the scenarios require caution as each province or region have different topographies and ecosystems, which require different adaptive measures to be applied. Secondly, each scenario, has both its environmental, social, economic benefits and costs, as a result policymakers should keenly weigh the tradeoffs for the most optimal outcome.

Overall, the approach developed here can be of critical importance to substantiate a business case for both public and private investment, particularly when the full-cost recovery of public investments is increasingly common. Furthermore, demonstrating economic welfare impacts to decision makers can help leverage public investment by catalyzing financing from both development and environmentally oriented international institutions. Our work quantified societal benefits, including the promotion of prosperity and enhancement of quality of life for all those involved in food and agricultural value chains from production to utilization and consumption. The integrated modeling approach can enhance understanding of policymakers, the scientific community, and a broader audience of conservation managers, government officials, and private sector managers by demonstrating the values of terrestrial ecosystem services in a natural capital context, and can inform the real-world decisions that they make.

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THE ECONOMICS OF LAND DEGRADATION

GREEN GROWTH Knowledge Platform

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