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Unpacking Ecological Stress from Economic Activities for Sustainability and Resource Optimization in Sub-Saharan Africa

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Abstract: Most sub-Saharan African (SSA) nations are governed by traditional economic models of using varied varieties of capital (including human), technological and natural approaches to supply goods and services. This has undoubtedly led to annual economic growth of about 3.2% in several African nations and higher per capita income as some of the major benefits, which have improved the standards of living and social wellbeing but conjointly have led to environmental degradation. In response to the environmental degradation problem, while benchmarking against international policies, this article evaluates approaches to economic development, environmental management, and energy production in the context of climate change. Case studies consider the mine-dependent nations of Zambia and the Democratic Republic of Congo (DRC) and the agriculture-dependent nation of Rwanda. In Zambia and DRC, energy efficiency in the mining and metals industries could increase the electrification rate in Zambia and DRC by up to 50%. Additional industrial utilization of solar or wind energy is key to a stable energy supply, economic development and environmental protection. In Rwanda, population growth and land constraints point to economic growth and agricultural improvements as the key to sustainability and sustainable development. These case studies emphasize resource optimization, energy efficiency, renewable energy deployment, strategies to reduce biodiversity loss and environmental degradation, and the improvement of social wellbeing for both present and future generations to achieve an ecologically enhanced sub-Saharan Africa.

Keywords: economic activity; sustainability; energy efficiency; green growth; economic growth; ecology; environmental degradation; Zambia; Democratic Republic of Congo; Rwanda

1. Introduction

As nations in sub-Saharan Africa (SSA) aspire to attain development, they tend to overexploit their resources in a manner that does not consider the environmental impacts, especially through major economic activities such as agriculture, energy production, and mining. These economic activities lead to an array of socioeconomic challenges including high resource consumption, diseases, urbanization, impoverishment, inequality and insufficient resources for all, alongside high population growth. All these challenges require careful analysis to resolve.

Previous research has highlighted the role of energy generation, agriculture and mining in global and regional greenhouse gas (GHG) emissions. Estimates of electricity and heat production, agriculture, forestry and land use, and the industry sector's contribution to global GHG emissions are about 35%, 24% and 21% respectively [1]. Since the energy sector globally contributes the highest GHG emissions, resolving emissions from the energy sector would enhance the global pursuit to combat climate change and attain a green economy. Similarly, in the SSA region, the energy sector is still the largest contributor of GHG emissions, with South Africa accounting for about 1.2% of the global emissions from coal-fired power plants [2] while the rest of the SSA nations contribute more GHG emissions from agriculture, forestry and other land uses [3], [4]. Energy underpins economic growth globally regardless of the levels of development achieved thus far. It is key to the production of food, the water supply and other goods and services globally [5]. The Organization for Economic Co-operation and Development (OECD) considers improving the environmental performance of energy as a critical step towards achieving green growth [6]. The International Energy Agency (IEA) calculates that with the right policies, the world can achieve over 40% GHG emission cuts if it uses sustainable, cost-effective energy technologies [7].

This study explores how economic activities in the sub-Saharan African region may impact the earth's finite resources and the environment, if not well-planned or if they are unsustainably implemented. An optimization framework can be adopted for the energy development, mining and agriculture sectors. Three research studies are developed in Rwanda, the Democratic Republic of Congo (DRC) and Zambia. In Zambia and DRC, the mining and technology industries can play a critical role as catalysts for sustainable energy development.

To complement the mining and energy sector, agriculture in SSA provides a context for analysis of ecological sustainable development in Rwanda.

2. Literature Review

The literature overviews four thematic areas: (a) resource efficiency, (b) green growth (c) ecological sustainable development and (d) synergies between energy, the environment and the economy. The review is limited to the case for how climate action (SDG 13) and sustainable economic activity rollout may enhance green growth and sustainable energy development (SDG 7), to promote ecologically sustainable economies in SSA (SDG 15).

2.1. Resource Efficiency

Population growth in SSA (2.7% as of 2018) increases the demand for energy, food, water and other natural resources [8]. This points to a requirement to pursue economic growth sustainably while keeping the environmental impacts in check and conserving natural resources [9]. Improved use of resources would conserve the Earth's finite resources and enhance sustainability and achieve economic growth with fewer resources [10]. A benefit of efficient resource usage is that it somewhat decouples economic activities from consumption and environmental impacts. [11].

2.2. Green Growth

The term green economy is synonymously referred to as green growth [12]. The OECD defines green growth as fostering economic development without mismanaging the natural resources and the environment on which life depends. Green growth aims to enhance sustainable investment and innovation as an approach to underpin economic growth [13]. The authors infer that green growth is significant to both developed and developing nations. The developing nations can seek to 'leapfrog' traditional economic solutions and embrace modern and cleaner technologies as they transition towards a green economy [12]. There is a need to enhance green growth to restore the ecological imbalance and deficits that are presented by the nexus pressures in SSA [14].

Robert C. Brears highlights six (6) critical characteristics of green growth as [6]:

i. to effectively use natural resources as nations, pursue economic growth,
ii. to value the ecosystems,
iii. to ensure that inter-generational economic policies are preserved,
iv. to increase usage of renewable energy resources,

v. to protect the earth and all that live in it from climate-related disasters,
vi. to reduce resource wastage.

These six characteristics point to the need to maintain a balanced ecosystem, use resources efficiently and reduce climate impacts and waste as nations migrate towards a green economy that is characterized by energy efficiency and use of renewable energy. The fact that Brears also incorporated inter-generational policies implies that these six points are compounding in nature.

2.3. Ecological Sustainable Development

The World Commission on Environment and Development emphasized during the Brundtland Commission's deliberations that nations need to be cautious over continued unsustainable economic growth which also demands global behavioral change [14,15]. The Brundtland Commission defines "sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition was modified in Australia to a concept which incorporates the environment-ecologically sustainable development. Ecologically sustainable development (ESD) is defined as: "using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be improved" [14]. Four main ecological processes are the water cycle, biogeochemical (or nutrient) cycle, energy flow and community dynamics, also referred to as succession [16]. These processes aid the circulation of minerals, oxygen and carbon dioxide between living things like plants and animals, and non-living things within the environment, thereby assisting in the maintenance of a balanced ecosystem that supports long-term biodiversity.

Ecological processes involve physical, biological and chemical processes to produce organic matter, drive soil formation, reproduce organisms and transfer carbon and nutrients between living and non-living organisms. At the same time, these processes also provide natural resources, food, fiber and timber and conjointly assist in the regulation of air and improvement of water quality [17,18]. Ecological sustainability (ES) is the capacity of an ecosystem to maintain important functions and processes and keep them in check with the biodiversity over the long-term.

The United States Environmental Protection Agency (EPA) frames the impacts of economic activities on the environment. Some economic activities that are harmful to the environment include the use of pesticide chemicals and industrial waste generation which may contaminate the air or water or cause damage to the environment [17]. Furthermore, economic activities such as wastewater treatment plant discharge, nutrients from fertilizers and animal manure, and ultraviolet radiation affect water quality. These activities disturb the communities where they occur and entire populations as well [16].

This issue of ecosystem disturbances can be addressed by adopting the principles of ecologically sustainable development [19]. The six main principles of ESD are:

i. sustainable use
ii. integration
iii. precautionary
iv. inter-generational and intra-generational equity
v. conservation of biological diversity and ecological integrity
vi. the internalization of external environmental costs.

In summary, a synergy exists between environmental degradation, climate change and green growth. Environmental degradation involves all agents that work against a healthy and balanced ecosystem. The idea of a green economy or green growth is aimed at maintaining a balanced ecosystem, promoting efficient usage of resources to reduce climate impacts and waste with an emphasis on energy efficiency and renewable energy usage.

In SSA, the highest GHG emitter is South Africa, which is 14th in the world, accounting for about 1.18% of the total global GHG emissions and 20% of the GHG emissions in SSA [2]. It is for this reason that most researchers often exclude South Africa from the discussion of GHG emissions in SSA. Figure 1 shows that the six top emission sources in SSA represent about 80% of all emissions, excluding South Africa [4].

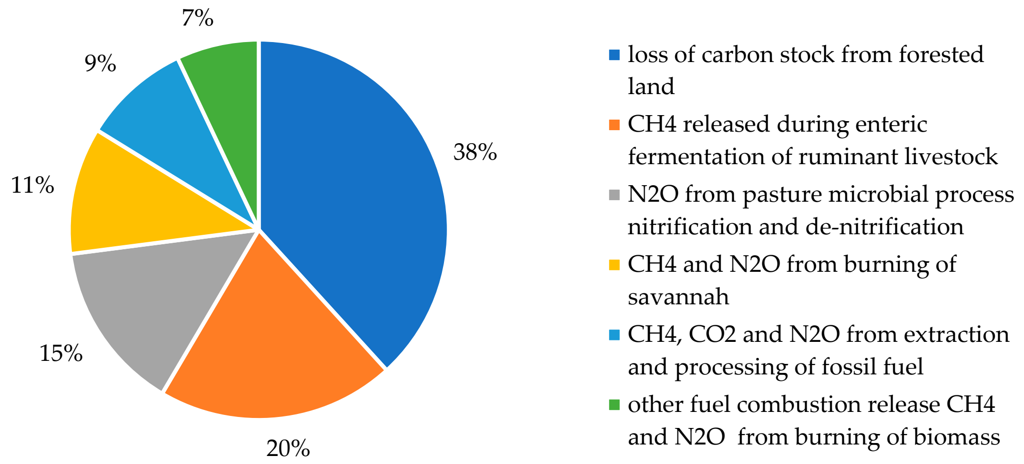

Figure 1. Greenhouse gas (GHG) emission sources in sub-Saharan Africa (SSA) excluding the Republic of South Africa.

Figure 1 shows that the highest carbon emissions in SSA are through forest carbon stock. The forest feedstock is carbon retrieved from the atmosphere and stored within the forest ecosystem, in living biomass, soil and even in deadwood and litter through the sequestration process [3].

A recent article by Molly Bergan highlights that climate change is a global problem that occurs in one location but affects those in other locations. What happens in the DRC forest basin may not affect the Congolese people alone but may affect the neighboring countries or even those in other continents. According to the Global Forest Watch, in 2018 deforestation in the Congo Basin was very high. Recent research by the University of Maryland suggested that at the current rate of tree cover loss, the DRC's primary forest could be completely razed by 2021. The studies further show that tropical rainforests like the Congo Basin, the Amazon and others worldwide positively assist in regulation of rainfall patterns by recycling the moisture in the atmosphere and reducing the surface temperatures in non-forested areas [20]. This emphasizes that climate change should be addressed as both a regional issue and as a global issue.

2.4. Synergies between Energy, the Environment and the Economy

The authors summarize this literature overview with a conceptual framework for the synergies between energy, economic growth and the environment. Figure 2 shows the research conceptual framework.

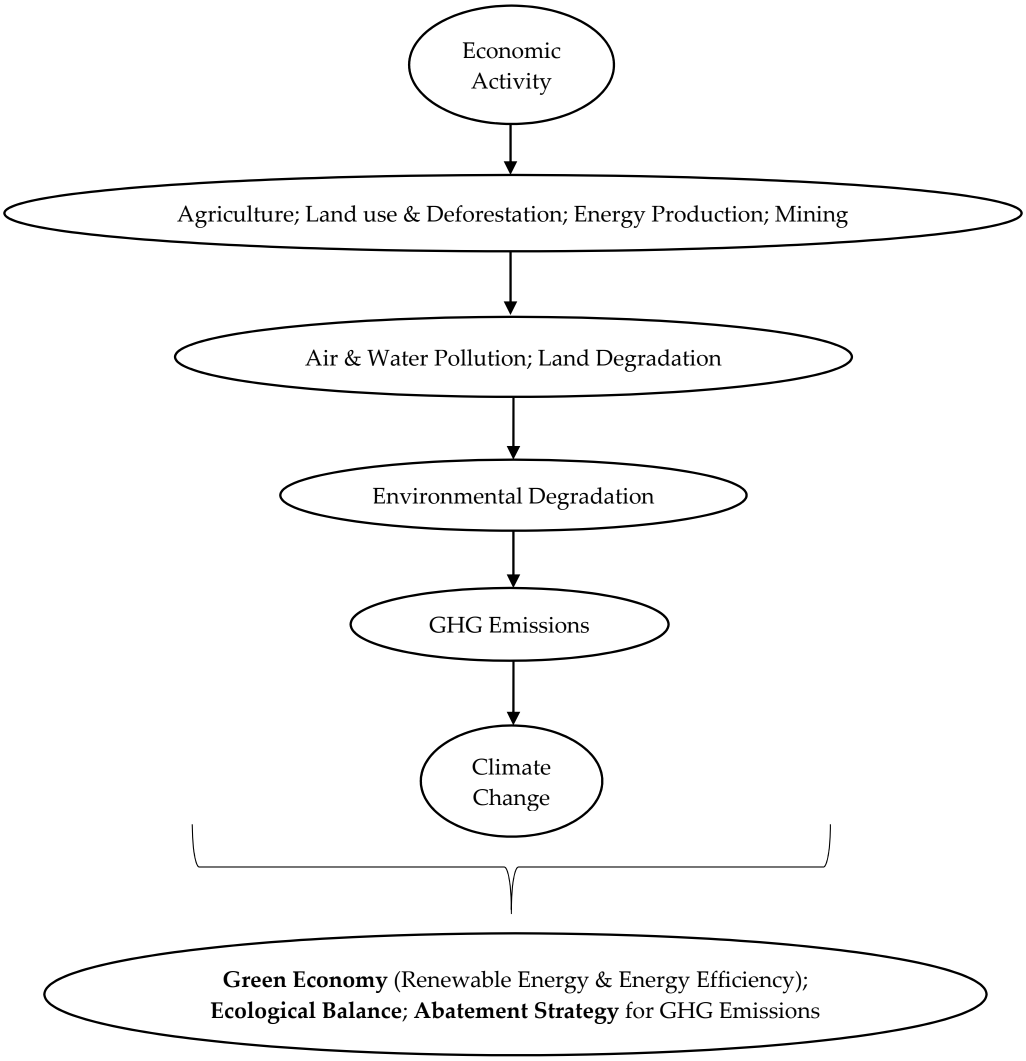

Figure 2. Research conceptual framework.

Figure 2 shows that the selected economic activities (agriculture, forestry and land use; energy production; and mining) may lead to land degradation and environmental degradation if unsustainably implemented. On the upside, Figure 2 shows that these issues of land degradation, environmental degradation and climate change will be evaluated against the following three critical dependent variables: (1) green growth, which emphasizes the use of renewable energy, energy efficiency and cleaner technologies; (2) ecological balance, which if disturbed can have significant environmental, economic, and social impacts; and (3) developing an abatement strategy to deal with the prevalent GHG emissions.

The OECD highlights that to improve environmental performance, there is a need to embrace green growth, the cornerstone of which is the usage of renewable energy. Furthermore, the demand for a reliable energy supply supports most economic activities in the world today, regardless of whether they are a manufacturing firm in Canada or a farming activity in Zambia [21]. Energy is needed in all sectors of the global economy and these can be reflected by the seventeen (17) United Nations Sustainable Development Goals (SDGs).

According to the World Health Organization's (WHO) report in 2008, the world records a high annual death rate with over 1.4 million people dying every year due to poorly combusted biomass fuel in households, mostly from developing countries. This is a strong reason for developing nations to foster green growth as country-specific strategies to avoid such premature deaths. Furthermore, the vehicles that are used for transportation use imported fossil fuels which are not just costly but are also a source of civil wars and air pollution. Although coal is cheap, burning it causes more harm to the environment than any other fossil fuel. Unsustainable land use, air pollution and water contamination by human activities like bio-energy production, mining and agriculture may impact ecosystems, food security and human health [21].

3. Materials and Methods

The study aims to provide a means to use the land, water, minerals and other finite resources efficiently and sustainably because they are non-renewable and essential to the socio-economic wellbeing of human, plant and animal life. To achieve this aim, a fourfold method is adopted to first identify the major country-specific economic activity and to second analyze their impact on the earth's finite resources such as air, water and land. Thirdly, we evaluate their impact against GHG emissions and climate change contributions. Fourthly, all these factors are analyzed and benchmarked against the principles of green growth, ecological sustainable development and an abatement strategy to reduce GHG emissions and climate change in SSA. Figure 3 shows the research method steps.

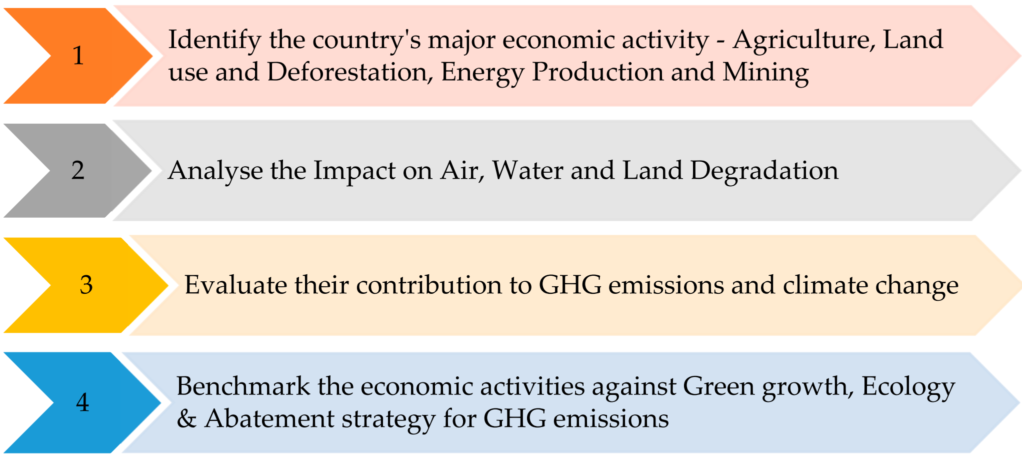

Figure 3. Steps to evaluate ecological stress by economic activities in SSA.

The case studies for this study are Rwanda, which is an agriculture-dependent nation with a high population density, Zambia, and the Democratic Republic of Congo (DRC), which are mining and mineral extraction-dependent nations with low population densities. Credible secondary data, previous studies, and statistics from government agencies and the World Bank are used. These case studies were chosen based both on the knowledge of the authors and to illustrate contrasting environmental and economic situations. Table 1 illustrates the contact between Rwanda and the Copperbelt countries of Zambia and DRC. The electricity data are from the energy authorities in each country and the population and land area figures are from international statistics.

Table 1. Electricity, land and population Statistics for Zambia, the Democratic Republic of Congo (DRC) and Rwanda.

	Zambia	**DRC**	**Rwanda**
Electrification Rate (%)	31	10	51
Total Electricity (GWh, 2018)	13,000	7000	720
Industrial Electricity (%)	54	57	29
Population (M)	17	81	13
Electricity per Person (kWh/capita-yr)	765	86	55
Land Area (thousand km^2)	753	2345	26
Population Density (people/km^2)	23	35	500
Land Area for Agriculture (%)	1.6	5.1	53.2

4. Agriculture: Rwanda Case Study

Step 1. Rwanda has an agricultural economy, with most agriculture at the household subsistence level without use of farm animals or agricultural machinery. One of the Rwanda's Vision 2050 goals is to migrate from subsistence farming to commercial farming in order to reduce poverty by 50%.

Step 2. Impacts of agriculture in Rwanda include soil erosion and water pollution. Most subsistence farmers do not grow the crops recommended by Rwanda's Vision 2050′s nutritional replenishment programs but instead resort to crops like cassava which can cause soil erosion when grown on slopes. Furthermore, the frequent field turnover of the preferred crops and the excess use of fertilizers exacerbates water pollution and land degradation.

Use of biomass for cooking has significant health effects, particularly for the women and children who stay close to the cooking areas. OECD projections and World Health Organization (WHO) surveys indicate that more than half a million people in SSA die annually from poor cooking methods, while millions suffer from chronic illnesses. So far, positive impacts from cookstoves are recorded in Mali, Ghana, Kenya and Ethiopia [22]. Some biomass in Rwanda is grown in agroforestry systems which can reduce pressure on forests but also takes land that could be used for agriculture. In addition, almost 1000 km^2 of wetland, nearly 4% of Rwanda's land area, is reserved for peat energy production, use of which would threaten wetland ecosystems while also increasing greenhouse gas emissions.

Alternatives to biomass for cooking (e.g., propane or electricity) are more expensive than biomass. Without more income, Rwandans cannot afford these alternatives. Without a transition from subsistence agriculture, Rwandans struggle to increase their incomes.

Step 3. According to Rwanda's 2012 Second National Communication to the UNFCC, agriculture is responsible for 78% of Rwanda's emissions. Forestry and land use change has both positive and negative components, with absorption of CO_2 due to Rwanda's reforestation programs, as well as emissions from increasingly intense forestry and land use change; overall net emissions from forestry and land use change are estimated by the world Resources Institute to be 11% of the total. The remaining emissions are from diesel used for some electricity production and industrial activities.

Step 4. To increase agricultural productivity and reduce environmental impacts including greenhouse gas emissions, the Rwandan government promotes terracing across the sloping landscapes, agroforestry, zero-grazing zones and efficient irrigation systems like drip-irrigation to improve water efficiency and land sustainability. The government also promotes efficient production of charcoal, which is a main form of biomass used for cooking. All of these policies support sustainable agricultural development in Rwanda.

With a density of 500 people per km^2, Rwanda's high population density is exacerbated by low-productivity agriculture and a reliance on biomass for cooking, both of which increase pressure on land resources. The annual population growth rate of 2.95% extends the challenge.

This tug-of-war between land settlement and farmland alongside energy production is a big challenge in Rwanda. Reducing population growth, reducing use of biomass for energy, reducing water pollution and increasing the productivity of agriculture are interrelated problems that can be addressed synergistically to support sustainability [23].

The case study on agriculture as an economic activity in Rwanda shows that higher population growths in SSA nations would increase energy, water, and food consumption, and these issues affect land use and ecological sustainable development in a compounding manner. SSA nations could measure the extent to which the demand for biomass of a region exceeds the country's utilization. By 2019, in SSA, out of forty-six (46) countries, eighteen (18) have a biocapacity reserve and twenty-seven (27) are in deficit [24]. This approach can create awareness in SSA nations that rapid population growth can follow either the economics paradigm, which is more concerned with population growth as a threat to resources like arable land and settlement land, or follow the neoclassical economics paradigm, which views population growth as a booster factor for technological and other changes that mitigate the effects of natural resource scarcity on socioeconomic wellbeing [23].

5. Mining Sector: Zambia and DRC Case Study

Step 1. The Central African Copperbelt (CAC), comprising the Democratic Republic of Congo (DRC) and Zambia, is the world's largest copper and cobalt producer. Both countries are economically dependent on the mining industry. The mining industry is also the main consumer of electricity in both countries. Most of the electricity is produced by hydropower, with additional power provided by diesel and other fossil fuels. As a result, the greenhouse gas emissions of the electric power sector are relatively low in both countries.

Step 2. The mining and metals industries in DRC and Zambia have extensive environmental and human health impacts. There is significant water pollution, land degradation, health impacts and ecosystem impacts, as described elsewhere in the literature.

Step 3. Table 2 shows greenhouse gas emissions in Zambia and DRC for 2016. Even though the mining and metals industries dominate the gross domestic product (GDP) of Zambia and DRC, their greenhouse gas emissions are low. With most of their electricity generated by hydropower, the DRC and Zambia are well positioned to provide low carbon energy to their populations. As will be discussed further below that while the mining and metals industries present substantial challenges concerning the overall environmental impacts from an energy perspective, it can also provide energy development opportunities in these countries.

Table 2. Greenhouse gas emissions from DRC and Zambia, 2016. Data from national emissions inventories.

	DRC ($MtCO_2e$)	DRC (%)	Zambia ($MtCO_2e$)	Zambia (%)
Land-Use Change and Forestry	167.09	74.69	452.93	91.57
Agriculture	26.61	11.93	28.6	6.09
Energy	15.1	6.74	7.77	1.42
Waste	14.13	5.96	3.37	0.68
Industrial Processes	1.9	0.68	1.31	0.24
Total	224.83	100	493.98	100
Emissions per person (t CO_2e/cap-yr)	0.01		0.04	

Step 4. Benchmarking the copper production in Zambia and DRC with the highest copper producer in the world, Chile, indicates the potential for energy efficiency improvements. Using energy data from DRC and Zambian energy authorities and international copper production data [25], Table 3 shows the energy efficiency of copper production in the Zambia and DRC in comparison to Chile.

Table 3. Energy requirement for copper production in Chile, Zambia and the DRC.

	Copper Production (M t/yr)	Electricity for Cu Production (TWh/y)	Production Method: Concentrate (%)	Production Method: SX-EW (%)	Energy Efficiency (GJ/t Cu)
Chile	5.6	22	63	33	39
Zambia	0.755	6.2	57	43	82
DRC	0.85	7	90	75	82

From Table 3, the copper production in Zambia and DRC potentially increases its energy efficiency by a factor of two using commercially available technologies [26]. The energy required for copper production does increase as ore grades decline, especially if copper concentrations fall as low as 0.1% [27]. Chile has had a declining ore grade from 1% to now about 0.5%, while that of DRC and Zambia is about 2.5% [28]. The results in Table 3 (39 GJ/t for Chile, 82 GJ/t for Zambia and 82 GJ/t for DRC) indicate that there is substantial potential for energy efficiency improvements in DRC and

Zambian copper production, in the range of a factor of two. If this were made available for other uses, the electrification rate in each country could increase by up to 50%.

In addition to energy efficiency, Chile has extensively deployed solar power in its copper production industry. Chile has substituted 100% of its grid electricity with solar energy technologies and this has reduced the global warming potential (GWP) of the pyrometallurgical (P-Cu) process by 62% to 63%, while that of hydrometallurgical (H-Cu) process is reduced by 76% [28].

There are three strategies from this research to reduce carbon emissions or achieve a zero-net carbon emission economy using renewable energy resources. These strategies are; (1) deploying greater energy efficiency throughout the production process to reduce costs and free up hydro-electricity capacity for other uses; (2) adopting more diverse types of renewable energy resources like solar, wind and geothermal energy to enhance power system diversification beyond hydro-electricity, and enhance the expertise in the electricity sectors in SSA, while conjointly reducing greenhouse gas emissions by displacing diesel back-up power; and (3) provide regional collaborative expertise for regional sustainable energy development within SSA [29]. However, degradation of hydropower systems and drought, possibly exacerbated by climate change, have reduced the reliability and availability of hydroelectricity. There is significant potential for increased efficiency in the mining and refining sectors in DRC and Zambia. This could free up electricity, generating capacity for greater energy access by the local population. Use of solar and wind energy in copper mining is also being heavily implemented in Chile, another leading copper producer, with innovations that could potentially be adopted in DRC and Zambia as well.

Because of the strong export market for copper and especially cobalt in its use in electric products, multinational firms can support sustainable development in DRC and Zambia by requiring adherence to environmental sustainability standards. Child labor standards have already been improved in the CAC mines due to the insistence of major electronics firms. Combining good governance with support for environmental sustainability and labor standards from international companies, as well as ongoing modernization of mining and refining operations, can be a pathway for development in these resource-dependent nations.

In Zambia and DRC, the mining and technology industries can promote sustainable energy development, and energy modelling simulations and engineering economics calculations can provide guidance on the opportunities for energy efficiency and high usage of renewable energy [30].

Hybrid renewable energy systems like solar-hydro energy production can displace the expensive and carbon-emission-intensive diesel generation as an alternative source in the mines while leveraging cheaper, zero-net carbon emission renewable energy resources. We suggest three strategies to progress toward a zero-net carbon emission economy using renewable energy resources. These strategies are: (1) deploying greater energy efficiency throughout the production process to reduce costs and free up hydro-electricity capacity for other uses; (2) adopting more diverse types of renewable energy resources like solar, wind and geothermal energy to enhance power system diversification beyond hydro-electricity, and enhance the expertise in the electricity sectors in SSA, while conjointly reducing greenhouse gas emissions by displacing diesel back-up power; and (3) provide regional collaborative expertise for regional sustainable energy development within SSA [29].

Multinational companies in the metals and technology sectors have strong sustainability and social responsibility programs that support the communities and environments in which they operate. A Lean Six SIGMA approach is also emphasized in SSA to reduce waste and/or dispose of the waste in a manner that does not degrade the environment. In all operations within firms in SSA, the three pillars of sustainability (the people, the planet and the profit) should always be upheld to achieve ecologically sustainable economies.

6. Research Significance, Limitations and Policy Implication

Some African nations, such as Rwanda, have a master plan strategy, e.g., Vision 2050, for green growth. These types of plans support improving and implementing land use practices such as expanding agroforestry, carbon crediting innovative financing mechanisms and payments-for-ecosystems services [31]. For the SSA region as a whole, comprising forty-six (46) countries, greater efforts are needed. In DRC, the levels of deforestation are higher than any other tropical forest nation globally; this affects the region and the world because forests regulate rainfall patterns. In some SSA nations like Zambia, forest management policies exist, but implementation is needed. This scenario is not unique to Zambia, but is common in most SSA nations. Further, stronger policies are needed within SSA nations concerning the effects of disturbing balanced ecosystems on the environment. The green growth concept can provide a pathway implementation of policies to support sustainability and subsequently sustainable development.

Improvements in SSA's green growth strategy and policies with emphasis on high usage of renewable energy resources and energy efficiency would allow better planning for water management, land use, and carbon footprint mitigation and trading programs using high-tech tools, cleaner technologies, solar micro-grid solutions and solar-hydro mixed energy generation systems because they are capable of improving sustainability in SSA. On a promising note, modern technology and software are rapidly being developed globally to aid SSA nations in developing advanced strategies and policies that would ensure that an ecologically sustainable SSA is achieved.

This study is limited to the three selected economic activities, agricultural forestry and land use in Rwanda, mining and sustainable energy in Zambia and DRC, and evaluates sustainable planning and implementation as a focus area for these economic activities in the spectre of climate change without quantifying the exact greenhouse gas emission contribution by these economic sectors. Future research is recommended on life cycle assessment (LCA) from cradle to grave in the mining industry in SSA and on agricultural activities and other land usage to quantify their GHG emission contributions. Detailed quantitative study of biodiversity losses are also needed in the entire SSA, especially in the agricultural sector because it is the most dominant economic activity in the region.

The significance of this research is in line with the just-ended IEA ministerial meeting resolution by global energy leaders in Paris, France, held on 6th December 2019, and the Conference of Parties 25 (COP 25) resolutions held in Madrid, Spain between 2nd December 2019 and 13th December 2019. These highlighted that the world recognizes the importance of energy security and clean energy transitions which can be addressed by strategies like green growth to resolve complex global issues like energy security, population growth, resource efficiency, urbanization, resource scarcity, climate change, sustainable consumption and sustainable energy production and energy access [32]. To enhance renewable resources, African governments were urged by COP 25 to plan natural resource usage and migrate towards lower carbon technologies to enhance a smooth transition to green economies.

7. Conclusions

Energy underpins the economy and is key to the production of food, the water supply and other goods and services in SSA and globally. While major economic activities in sub-Saharan countries support development, they may conjointly lead to loss in biodiversity, air pollution, resource inefficiency, GHG emissions, energy-food-water-land stress and other waste, if they are unsustainably implemented.

This research showed that optimizing the agriculture, land use change and forestry will improve sustainability in SSA. To further enhance sustainability in sub-Saharan Africa, nations are advised to establish a balance between the social, economic and environmental sectors of their societies to cater for both the present and the future generations.

A green growth approach alongside sustainable ecological principles and a GHG abatement strategy are the elements for ecological sustainable development in sub-Saharan Africa. The nations in SSA can simultaneously pursue sustainable energy development (SDG 7) without compromising the environment, with ecological sustainable development (SDG 15), alongside greenhouse gas abatement approaches for climate action (SDG 13), especially if supported by stronger regional and global policies.

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