

Research Article

Greenhouse Gas Emissions and Mitigation Measures within the Forestry and Other Land Use Subsector in Malawi

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Analysing past trends of greenhouse gas (GHG) emissions remains indispensable to the understanding of current GHG emissions, thereby enabling prediction of future emissions as well as development of their mitigative pathways. This study quantified GHG emissions within the Forest and Other Land Use (FOLU) subsector in Malawi for the period 2011 to 2020. Results indicate that Malawi's GHG emissions in the FOLU subsector fluctuated but decreased by 0.84 MtCO₂e (13%) from 2011 to 2020, averaging to -1.3% annually. The GHG emissions of different categories within the subsector were highly significant ($p < 0.001$) and contributed the highest (99.72%) of the total variation. Forestland contributed the highest (74%) of the subsector category emissions, followed by biomass burning (19%). The uncertainties for the estimated GHG emissions were low (<15%). This shows that the estimated GHG emissions within the FOLU subsector were significantly minimised. Notable interventions that have abated the emissions include afforestation and natural/assisted regeneration; protection and conservation of protected areas through the REDD+ mechanism; establishment of seed banks for raising drought-tolerant tree species; and breeding of fast-growing and drought-tolerant tree species; as well as screening of disease and pest-resistant species and promotion of biological control.

1. Introduction

Climate change, largely attributed to anthropogenic activities, remains a critical global phenomenon that attracts the attention of policy makers as well as researchers in all dimensions. This challenge has triggered a nexus of problems and constraints that hinge on societal, cultural, gender, and ecological dynamics. Precisely, these have culminated to a plethora of catastrophes associated with ecological imbalances, global warming, and extreme weather conditions (rise in sea level, floods, hurricanes, droughts, heatwaves, cyclones, and hailstorms), resulting in poor economic growth, insecurity, and retrogressive technological advancement [1–4]. Increasing concentration of greenhouse gas (GHG) emissions is considered as a key cause for these issues [1, 2]. Recent studies have specified and quantified three main greenhouse gases (GHGs) which significantly impact the environment, namely, carbon dioxide (CO₂) at 407.8 ± 0.1 ppm, methane (CH₄) at 1869 ± 2 ppb, and nitrous

oxide (N₂O) at 331.1 ± 0.1 ppb [3, 5]. Accordingly, reducing GHG emissions has become a key agenda of the global community.

The paradox about reducing GHG emissions is that developing countries still remain disadvantaged due to limited access to funding and technologies, a predicament that jeopardises the understanding and estimation of the emissions [4]. In the tropical dry Forestlands of Southern Africa Development Community (SADC) region, most country member states have embraced reducing emissions from deforestation and forest degradation (REDD+) as a remedy to the climate change effects [6]. Malawi, a SADC associate, categorises key sectoral sources of GHG emissions as follows: (i) Industrial Processes and Product Use (IPPU), (ii) Waste, (iii) Energy, and (iv) Agriculture, Forestry, and Other Land Uses (AFOLU) [7], while the AFOLU sector is the key contributor of GHG released into the atmosphere, and the Forestry and Other Land Uses (FOLU) subsector activities are not only affected by climate change but also

contribute to the phenomenon [8, 9]. GHG emissions and removal from FOLU consist of CO₂ and non-CO₂ gases (methane and nitrous oxide) [4].

In Malawi, primarily, although not exclusively, the FOLU subsector's contribution remains the most significant. The contribution of FOLU to the total Malawi emissions has been documented in a number of technical reports [7, 10]. It has been estimated that FOLU alone accounts for 56% of the total Malawi GHG emissions (in the year 2011) [7]. Within the FOLU subsector, emissions from forestlands contributed 70% of the sector emissions [10]. On the contrary, forests in Malawi play significant roles within the economic, social, and ecological domains. Malawi's forests cover 23,677 km² (25%) of the total surface land area. Out of the entire forest area, the Miombo woodlands cover 22,857 km², while plantation forests take up the remaining 820 km². Pine and eucalyptus are dominant in the plantations, while *Brachystegia* is the most prevalent tree genus in Miombo woodlands [11]. It is estimated that more than 96% of Malawi's population use wood fuels (charcoal and firewood) for household cooking and heating. Apart from energy, forests provide timber and nontimber forest products as well. In addition, forests contribute 6.9% to Malawi's GDP through domestic and export product sales, employment, and tourism [11, 12]. While demand for forest products is expected to continue to increase, a recent study has projected that, between 2019 and 2025, Malawi's demand for wood fuel will exceed the sustainable supply [12]. Therefore, actions have to be taken to satisfy this demand while, at the same time, controlling adverse effects on the environment.

It is indicated that analysing past trends of GHG emissions has become a useful tool towards the understanding of current GHG emissions and aids in predicting future emissions as well as in development of emission mitigation pathways. It is further predicted that if proper focus is not given to GHG emissions, the current trend is likely to increase even further in the nearby future [13–16]. In this context, Malawi's past scenarios of GHG emissions were only documented from 1990 to 2011 [10]. The challenging problem arising in this domain is that the trend from 2011 to 2020 is not available in the literature thereby creating a scientific knowledge gap that would have helped in developing GHG emissions' mitigation. It is against this background that this study was conducted to quantify the GHG emissions within the FOLU subsector in Malawi for the period 2011 to 2020. Specifically, the study was executed to (1) determine the trend of GHG emissions from 2011 to 2020 within the FOLU subsector in Malawi, (2) determine the contribution of GHG emission within the FOLU subsector, and (3) discuss their emission mitigation measures.

2. Materials and Methods

2.1. Study Area. Malawi is located in Southeast Africa. It is bordered by Mozambique on the east and southwest, by Tanzania on the north and northeast, and by Zambia on the west and northwest (Figure 1). Malawi has a subtropical

climate, and it is categorized into three seasons, namely, hot-dry, warm-wet, and cool-dry seasons. Hot-dry season is evident from September to October with an average temperature range of 25°C to 37°C. Warm-wet season lasts from November to April with an annual average rainfall range of 725 mm to 2500 mm. This is the season during which 95% of the annual rainfall occurs. In alternation, the cool-dry season stretches from May to August with an average temperature range of 4°C to 10°C. In the cool-dry season, especially in June and July, frost may occur in isolated areas [17].

2.2. Data Collection. Records of the National Forest Monitoring System (NFMS) kept by the Forestry Research Institute of Malawi (FRIM) and Department of Forestry Headquarters, GIS Unit Section, for the period, January 2011 to December 2020, were used for this study. The records were collected monthly during the stated period and comprised areas burnt by forest fires, land cover change, and wood and fuelwood removal. The datasets obtained were manually populated into IPCC Inventory software version 2.691 to estimate GHG emissions and uncertainties. IPCC Inventory software implements the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Software can be used for the whole inventory or just individual categories, it allows different sectors of the inventory to be developed simultaneously, and it gives users the flexibility to use their own country-specific information [18].

2.3. Data Analysis. Datasets on GHG emissions and uncertainties were tested for normality and homogeneity with Kolmogorov–Smirnov D and normal probability plot tests. After the two criteria were met, the datasets were subjected to analysis of variance (ANOVA). Variance components for the sources of variation were also estimated. Statistical analysis was performed using GenStat 18.1 for Windows. Differences between treatment means were separated using Fischer's least significant difference (LSD) at the 0.05 level. Graphs were plotted using Microsoft Excel 16. The data were analysed using the following model:

$$Y_{ijk} = \mu + T_i + C_j + (TC)_{ij} + e_{ijk}, \quad (1)$$

where

- (i) Y_{ijk} is the response variable (GHG emissions or uncertainties) of the j th observation in the i th treatments,
- (ii) μ is the overall mean,
- (iii) T_i is the fixed effect of time in years ($i = 2011, 2012, 2013, \dots, 2020$),
- (iv) C_j is the fixed effect of categories of the FOLU subsector ($j =$ biomass burning, cropland, forestland, and grassland),
- (v) $(TC)_{ij}$ is the effect of the interaction between time in years and categories of the FOLU subsector, and
- (vi) e_{ijk} is the random residual effect, $e_{ijk} \sim N(0, \sigma e^2)$.

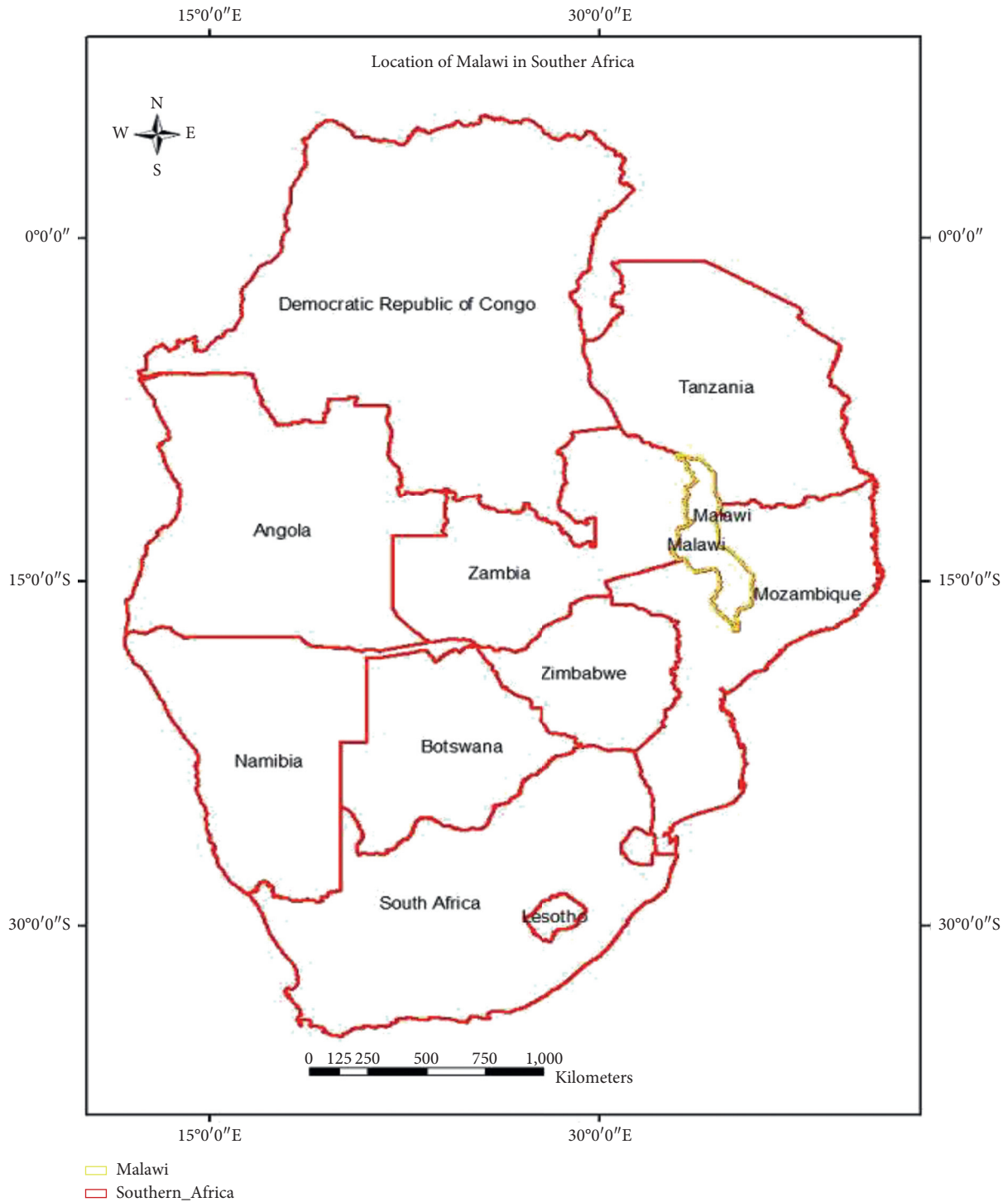


FIGURE 1: Location of Malawi in Southern Africa.

3. Results and Discussion

3.1. Trend of GHG Emissions within the FOLU Subsector in Malawi (2011–2020). A summary of the results on the trends of GHG emissions within the FOLU subsector in Malawi (2011–2020) is presented in Table 1 and Figure 2. The findings indicate that there were significant differences ($p < 0.05$) in GHG emissions among different years.

However, years contributed only 0.12% to the total variation (Table 1). The emissions fluctuated but decreased by 0.84 MtCO₂e (13%) from 2011 to 2020, averaging to –1.3% annually (Figure 2). The present results in the decrease of GHG emissions in the FOLU subsector are slightly higher compared to the previous results (1990–2011) of –0.6% annually [10]. The continuous decrease of GHG emissions in the FOLU subsector may have been driven primarily by

TABLE 1: Variance components for GHG emissions and uncertainty.

Source of variations	df	GHG emissions		Uncertainty	
		<i>p</i> value	Var %	<i>p</i> value	Var %
Ti	9	0.035	0.12	0.372	24.79
Cj	3	<0.001	99.72	0.280	9.75
(TC)ij	27	0.500	0.15	0.501	65.42

Ti is the time in years; Cj is categories of the FOLU subsector; (TC)ij is the interaction between time in years and categories of the FOLU subsector.

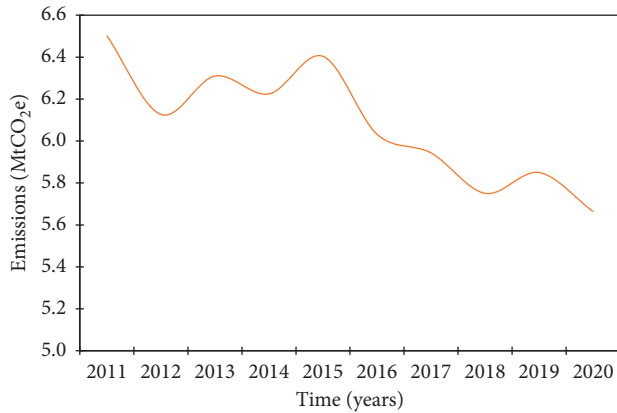


FIGURE 2: Average annual change in GHG emissions in the FOLU subsector in Malawi (2011–2020).

changes in the forestland category [19]. Nevertheless, Malawi's forest resources face large pressure from deforestation and forest degradation. According to Malawi's SNC [7], the major proximate and underlying causes of deforestation include high population growth, forest fires, increased fuel demand, and infrastructure development, not to mention agricultural expansion.

3.2. Categorical Contributions of GHG Emissions within the FOLU Subsector in Malawi. Results on the contribution of GHG emission within the FOLU subsector are presented in Table 1 and Figure 3. GHG emissions within different categories of the FOLU subsector were highly significant ($p < 0.001$) and contributed the highest (99.72%) of the total variation. Within the FOLU subsector, forestland contributed the highest (74%) among the category emissions, followed by biomass burning (19%) and then cropland (5%). Grassland contributed the least (2%) of the category emissions. The present findings agree with those reflected in the literature following a number of studies [7, 10]. The USAID [10] and Malawi's SNC [4] reported that, within the FOLU subsector, land category contributed 70% of the entire emissions in 2011. The slight increase (4%) of GHG emissions from forestland could be attributed to the population's heavy reliance on biomass energy for cooking and heating [12]. According to the USAID [12], it is estimated that more than 96% of Malawi's population use wood fuel for household cooking and heating.

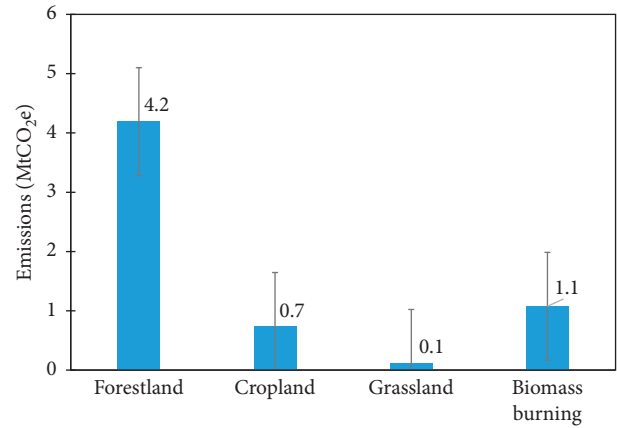


FIGURE 3: Malawi's GHG emissions by the FOLU subsector (2020).

TABLE 2: Uncertainty by year and FOLU categories.

Year	Uncertainty (%) by category				Mean
	Forestland	Biomass burning	Cropland	Grassland	
2011	9.77	9.23	8.76	8.93	9.17
2012	8.92	8.93	9.34	9.01	9.05
2013	9.29	9.99	8.03	9.05	9.09
2014	8.67	9.56	7.99	8.67	8.72
2015	9.23	10.2	9.54	9.06	9.51
2016	9.06	8.93	8.77	8.93	8.92
2017	8.95	7.98	9.43	7.92	8.57
2018	8.94	8.95	9.24	9.45	9.15
2019	9.87	9.31	8.97	9.13	9.32
2020	9.06	9.78	9.89	8.36	9.27
Mean	9.18	9.29	9.00	8.85	

3.3. Uncertainty Analysis by Year and FOLU Subsector. Uncertainty estimates for GHG emissions within the FOLU subsector are presented in Table 2. Results indicate that the uncertainties were low (<15%). This shows that the estimated GHG emissions within the FOLU subdomain in the present study were significantly minimised. GHG emission estimation is always associated with uncertainties, and it is essential to minimise them [20]. Sources of error in the estimation of GHG emissions are associated with calculation methods and modelling [20–23]. Calculation method error was minimised by employing 2006 IPCC software version 2.691. Appropriate use of software leads to calculation method errors which are normally distributed and have minimal effect on the final GHG emission determination [23]. The use of site-specific allometric modelling in the present study also helped to minimise the uncertainties. The site-specific allometric models significantly ($p < 0.001$) differed from the default allometric model used by other researchers [18] in the same site. The uncertainties for the default allometric model were high (>22%). The recommended uncertainty for the REDD+ mechanism is less than 15% at 95% confidence interval [18].

3.4. Climate Change Mitigation Measures. Classified as one of the least developed countries in Africa, Malawi is not

obliged to reduce its GHG emissions. However, the country continues to explore innovative measures to abate GHG emissions that emanate from FOLU through technological and policy interventions in order to mitigate and adapt the impacts of climate change. Some of the key interventions that have contributed to the gradual decrease of GHG emissions within the FOLU subsector include the following.

3.4.1. Afforestation and Natural/Assisted Regeneration.

The mitigation actions that enhance afforestation and natural/assisted regeneration are projected to result in the unconditional sequestration of approximately 1 million tCO₂e annually through planned afforestation in plantations and on customary land [24]. The projection is based on the recent afforestation rates. Since 2011, 50 plus million trees have been planted each year in Malawi (Table 3). Planting of different tree species has been done entailing all land tenure categories of Malawi that include state-owned forest plantations and reserves, customary lands, and private-owned lands and/or estates. As of date, a substantial 60% survival rate has been reported [25].

In addition, Malawi has an international target of conserving and managing a total of 3.5 million hectares that it pledged to contribute to the African Forest Landscape Restoration Initiative (AFR100). The target was committed to pan-African, a country-led effort to restore global 100 million hectares of degraded and deforested landscapes by 2030. Malawi seeks to build on past and current efforts to conserve and manage forests, among others, through the National Forest Landscape Restoration Strategy (NFLRS) [11]. Under this initiative, the country has identified and mapped degraded sites in every district to address vulnerability to climate change, adapt, and mitigate through integrated landscape management approaches to forest landscape restoration. The NFLRS has developed the following forest-based restoration interventions: (i) establishment and management of community forests and woodlots; (ii) forest management (forest reserves and plantations); and (iii) rehabilitation of stream and river banks.

3.4.2. Management and Conservation of Protected Areas.

In addition to the routine management of forest reserves, national parks, and wildlife reserves, Malawi established a national framework/policy on REDD+ that ably guides, monitors, and informs future actions on GHG emissions emanating from forestlands and associated land uses. After her formal acceptance as an UN-REDD partner country in March 2014, Malawi continues to estimate carbon and other GHG emissions from other categories including FOLU. This forms part of the national GHG accounting and reporting system that, as a signatory to the Kyoto Convention, obliges the country to report to the United Nations Framework Convention on Climate Change (UNFCCC).

In this respect, implementation of the REDD+ initiative has involved the Malawi Government to engage various partners in monitoring forests and the associated GHG emissions notably through a number of projects and studies (Table 4).

TABLE 3: Annual tree planting trends in Malawi (2011 to 2019).

Year	Quantity planted	Area planted (Ha)
2011	53,941,221	21,576.0
2012	52,334,642	20,934.0
2013	57,507,938	23,003.0
2014	63,196,846	25,279.0
2015	52,395,006	20,958.0
2016	52,343,450	20,937.0
2017	63,912,740	25,565.1
2018	62,531,346	25,012.5
2019	63,876,257	25,550.5

Source: Ministry of Natural Resources [26].

3.4.3. *National Forest Reference Level-2019.* In recognition of Decision 1/CP.16 adopted at the UNFCCC Conference of Parties (COP) in 2010, identifying national reference emission levels (REL)/reference levels (RL) has become an integral prerequisite for parties aiming to undertake activities under the REDD+ umbrella. In this vein, Malawi conducted its own National Forest Reference Emission Level (FREL) study in 2019 and submitted its report to the UNFCCC. The report serves as an interim document, detailing the proposed FREL activities. These include historical period it represents, associated activities, methodologies applied for deriving the estimates, and key assumptions and rationalisations that underpin the decisions made [26]. More importantly, it explains the role of Malawi's National Forest Monitoring System (NFMS), a structure task charged with the responsibility of tracking and regularly reporting greenhouse gas emissions and removal from REDD+ activities. Strikingly, it serves as an entry point through which mitigation and adaptation interventions can be integrated. Indispensably, this also ensures that accounting methods and procedures are compliant with the Intergovernmental Panel on Climate Change (IPCC) principles and guidelines of transparency, consistency, comparability, completeness, and accuracy [26].

3.4.4. Establishment of Seed Banks for Raising Drought-Tolerant Tree Species.

Tree seed banks remain important for the development of the forest sector as far as the regeneration and sustainability of tree species is concerned. In response to the call on the need to develop drought-resistant species, FRIM in conjunction with the Mulanje Mountain Conservation Trust (MMCT) has within the period in question established tree nurseries and seed research plots of *Widdringtonia whytei* (Mulanje cedar) in Mulanje, Dedza, and Viphya Plantations. Indigenous to Malawi, this particular *W. whytei* germplasm serves to suit the dynamic climate that is becoming warmer and drier in Malawi. In other words, the species has been developed to adapt trees to the low and marginal rainfall conditions that are being experienced in the country. Additionally, FRIM, through other initiatives such as Millennium Seed Bank Project and Kew Garden, UK, has also engaged in conservation of the country's rare, endangered, and endemic tree species' seeds for future replanting exercises [27].

TABLE 4: REDD+ and other related activities for measuring of GHG emissions in Malawi.

Study/initiative	Period	Focus	Locality
Avoiding unplanned mosaic deforestation and degradation in Malawi	2008-2009	Forest biomass and carbon assessments (REDD+ technology transfer)	Mkuwazi Forest Reserve and Nyika National Park
Tree planting and management for carbon sequestration and other ecosystem services	2006-2011	Forest biomass and carbon assessments	Countrywide
Forest resource mapping under the Forest Preservation Programme (FPP)	2010-2012	Forest biomass assessments and promoting of technology transfer on REDD+	Central, southern, and northern regions (17 forest reserves)
Lake Chilwa Basin Climate Change Adaptation Programme	2010-2014	Secure livelihoods and enhance resilience natural resource base through REDD+	Lake Chilwa Basin (Machinga, Phalombe, and Zomba)
Integrated Assessment of Land-Use Options in Malawi (IALUO) of LTS land cover/change map	2012	Assessment of land-use options and land cover/change map	Countrywide
Development of integrated monitoring systems for REDD+ in the Southern African development community project (SADC-GIZ MRV project)	2013-2014	Development of integrated MRV systems for REDD+ and/or forest ecosystems in the SADC region	Transboundary area between Eastern Zambia-Malawi border to Central Western Malawi (Kasungu National Park through Nkhotakota Wildlife Reserve)
Liwonde, Ntchisi, and Perekezi forest reserves inventory	2016	Forest biomass and carbon assessments	Liwonde, Ntchisi, and Perekezi forest reserves
Thuma and Dedza-Salima escarpment forest reserves inventory	2017	Forest biomass and carbon assessments	Thuma and Dedza-Salima escarpment forest reserves
National Forest Inventory	2018	Forest biomass and carbon assessments	Countrywide

3.4.5. *Breeding of Fast-Growing and Drought-Tolerant Tree Species.* Malawi's SNC [7] recommended a coordinated research approach to tree breeding and indicated the need for developing suitable species for the predicted warmer and drier environments in the future. In response, FRIM outsourced fast-growing hybrid pine seeds (*Pinus patula*, *Pinus kesiya*, and *Pinus oocarpa*). These were genotypically improved breeding material of the 4th and 5th generation which mature faster compared to the earlier generations. The germplasm is high yielding, drought, and disease tolerant. It has been planted on a trial basis in Zomba, Dedza, and Vipha Forest Plantations as a response to the climate change phenomenon that Malawi continues to experience.

3.4.6. *Screening of Disease and Pest-Resistant Species and Promotion of Biological Control.* Threatening the forest carbon sink in Malawi has been disease and pest infestation. Of late, *Eucalyptus* species have been adversely infested by *Glycaspis brimblecombei* nymphs and adult pests that cause damage by sucking plant phloem sap [28]. In spite of this, *Eucalyptus* species are highly preferred due to their robust growth and their multiple uses and nature, i.e., firewood, poles, medicine and being resistant to fire, and drought spells. Locally, these attributes render their management key to climate change mitigation and adaptation. Ongoing research by FRIM to establish the relative susceptibility of some of the *Eucalyptus* species to other pests, precisely *Leptocybe invasa*, indicates that there is less susceptibility of the pest for adoption in tree planting initiatives [29, 30]. As a mitigation measure, biological control research is also underway for *L. invasa* infestation, and FRIM procured *Selitrichodes neseri*

as a biological controller of the pest. The biological controller was released in October 2016, but the results on its effectiveness have not yet been documented. Another option recommended is the planting of higher-resistance tree species such as *Eucalyptus citriodora* [28].

3.4.7. *Multisectoral Approach.* The USAID [12], through a synthesis of statistics generated from various government surveys, observed a general increase in the proportions of households using firewood and charcoal in both urban and rural areas. The Malawi Government acknowledges the high dependence on biomass energy, with a focus on charcoal that is relatively more destructive. Charcoal production is believed to have contributed to impeccable levels of deforestation and degradation throughout the country. In response, the government developed the National Charcoal Strategy (NCS) in 2017 that caters for both medium and long term scheme [31]. The strategy aligns a multisectoral framework and an approach that focuses on pillars that define opportunities to incrementally address problems of charcoal production and demand [31]. The ultimate goal is to arrest and reverse the rate of deforestation and forest degradation that will eventually mitigate emissions that originate from the use of tree biomass as energy.

The NCS has proposed plans of action, otherwise known as pillars, for the period 2017-2027, which serve to mitigate GHG emissions that emanate from the FOLU domain. These are also interrelated to the energy sector, and they primarily but not exclusively include promotion of alternative household cooking fuels, sustainable wood production, and adoption of fuel-efficient cook stove technologies such as the Chitetezo Mbauula. The stove is locally made in Malawi, and it

is designed to consume less amount of wood biomass compared to other stoves thereby contributing to the reduction of emissions from woody biomass at a lowest level.

4. Conclusion

The present study has shown that Malawi's GHG emissions in the FOLU subsector fluctuated but decreased by 0.84 MtCO₂e (13%) from 2011 to 2020, averaging to -1.3% annually. GHG emission within the categories of the FOLU subsector was highly significant and contributed the highest (99.72%) of the total variation. Forestland contributed the highest (74%) of the category emissions, followed by biomass burning (19%), and then cropland (5%). Grassland contributed the least (2%) of the category emissions. The uncertainties for the estimated GHG emissions were low. This shows that the estimated GHG emissions within the FOLU subsector were significantly minimised. Some of the interventions that have helped the continuous decrease of GHG emissions in the FOLU subsector include afforestation and natural/assisted regeneration; protection and conservation of protected areas through the REDD+ mechanism; establishment of seed banks for raising drought-tolerant tree species; and breeding of fast-growing and drought-tolerant tree species; as well as screening of disease and pest-resistant species and promotion of biological control.

Data Availability

The data that support the findings of this study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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