Available online at https://asric.africa/agricultural-sciences
ASRIC Journal on Agricultural Sciences Vol.4(1)(2023) 48-59

Analyzing the Effects of Fuel-wood use on Forest Degradation and Carbon Loss, and Future Policies for Sustainable Energy Utilization in the War-Affected Areas of Ethiopia

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Received 18 April 2024; revised 15 May 2024; accepted 07 June 2024

Abstract
The armed conflict in Tigray/Ethiopia has resulted in a total dependence of residents on the scarce forest resources for energy use. Hence, in this study, we monitored fuel-wood transported to three major towns for two seasons and seven consecutive days. The study results showed that fuel-wood transported from the natural forest to each of the studied towns during the war was 16,055 ton per year, which was 628.7% higher compared to the pre-war. The resulting annual average number of trees cut to deliver fuel-wood to each town was 39,563 trees, far beyond the 5429 trees before the war outbreak. Hence, an equivalent of 268-365 hectares of forest at the proximity of each studied town disappeared every year. These in turn resulted to an average annual CO_2 emission of 27692.4 ton compared to 3800.2 ton before the war. To overcome these challenges, a set of five policy recommendations emerged, i.e. issuing fuel-wood permits and regulations; promoting Watershed protection and fuel-wood production approach; improving fuel-wood management and conversion practices; emphasizing on market potential of reforestation activities; encouraging and incentivizing alternative energy sources. It can be concluded that the war and existing siege in Tigray resulted to high forest degradation and carbon loss.
Keywords: fuel wood, forest, carbon, future policy, war affected, season

1. Introduction

Forests constitute important stocks of natural capital by generating benefits including timber, fuel wood, natural erosion regulation, biodiversity and combat climate change (Turner and Daily, 2008; Gibbs and Herold, 2007). They also generate at least 20% of the disposable income of landless and poor families worldwide (Agroforestry-Center, 2011; Schroeder-Wildberg and Carius, 2003), and up to 10% of the gross domestic product of 19 African Nations (World-Agroforestry-Center, 2009). However, these resources are challenged by severe degradation/deforestation (Hosonuma et al., 2012; FAO, 2010; UN-FAO, 2007). Studies showed that Africa's deforestation rate is twice the average in the rest of the world (FAO, 2010). These in turn lead to greenhouse gas emissions (Hosonuma et al., 2012). Taking Ethiopia as an example, the dependency on biomass resulted to an increased CO_2 emission from 5.1 million tons in 2005 to 6.5 million tons in 2010 (Mondal et al., 2018).

Fuel-wood collection and armed conflict represent the major drivers of forest degradation (Dresen et al., 2014; Skutsch et al., 2011). For example, Ethiopia has lost 140,000 hectare natural forest annually in the years between 1990 and 2010, and fuel-wood collection played an important role in the process (FAO, 2010; Haile et al., 2009). Findings also revealed that nearly half of all African countries have recently been embroiled in civil war (Gleditsch and Salehyan, 2006). In Tigray (northern Ethiopia), the armed conflict which was put in action in November 2020 has resulted in more than 500,000 fatalities, more than 2.2 million people internal displacement, more than 120,000 individuals sexual abuse, and more than 6 million people in need of emergency food aid. All basic services such as banking, telephone, electricity and transport were also immediately suspended after the war broke out (Abay et al., 2022).

While war's adverse effects on human and physical capital have been documented, evidence of its impact on the environment was scant, and the qualitative data collected so far present a mixed story: i) war leads to deforestation; ii) war conserves forest; iii) war has no any relationship with deforestation. These in support of the negative effects of war argued that war creates a power vacuum and breaks down conventional forest management regimes, fostering illegal logging and other resource conflicts (Hoffmann et al., 2018; Castro-Nunez et al., 2017; Fergusson et al., 2014; Allnutt et al., 2013; Glew and Hudson, 2007; McNeely, 2003; Renner, 2002; Kanyamibwa, 1998). A second hypotheses in the opposite direction pointed out that war protects forests by raising the costs of extraction and sale while simultaneously lowering the expected economic returns to farming (Burgess et al., 2015; Richards, 2005; Alvarez, 2003). The third argument revealed no interaction exhibited between armed conflict and forest transitions (Landholm et al., 2019; Ghilardi, 2016; Ordway, 2015; Bensel, 2008). Previous studies also used personal observations, historical accounts, and spatially explicit forest measurements for forest degradation and war relationship assessment (Rudel et al., 2015; Raleigh and Urda, 2007; Draulans and Krunkelsven, 2002). However, the impacts of fuel-wood collection on forest degradation are difficult to quantify even with sophisticated methods (Herold et al., 2011). The valuation of the actual amount of fuel-wood usage and its influence on forest degradation has subsequently been difficult to determine and remained the subject of significant discussion (Mwampamba et al., 2013). Furthermore, the quantity and type of fuel-wood use and associated carbon loss is expected to vary based on seasonal variation and availability of other sources (e.g. cow dung), which calls for further research.

To build a sustainable support to communities, there is a clear need to assess forest degradation for fuel-wood use as well as its environmental risks. Such studies are very important in order to: i) improve our knowledge about the level and impact of fuel-wood consumption and collection on the environment, ii) know the extent to which specific plant communities have been depleted due to wood conversion for fuel-wood purposes. In this study, we monitored fuel-wood transported to towns in Tigray (northern Ethiopia), so as to examine evidence of war's impact on forest degradation and carbon loss. We also collected a set of policy recommendations from series of discussions and review of literatures and policy documents.

2. Materials and Methods

2.1. The Study Area

The study was conducted in three major cities of Tigray (northern Ethiopia), namely: Mekelle (13°29'48"N and 39°28'36"E), Wukro (13°47'32"N and 39°36'13"E) and Maichew (12°47'02"N and 39°32'25"E). These towns are located at the shoulder of the East African Rift Valley, along the Addis Ababa – Asmara main road (Fig.1). The Tigray province belongs to the African drylands (African Sahel), which are often referred to as the *Sudano-Sahelian* Region (BoPED, 1998; Hunting-Technical-Service-Ltd, 1976).

Figure 1. Location of the selected towns in Tigray and Ethiopia

The vegetation cover in the area mostly consist of dense stands of native species like *Juniperus procera*, *Olea africana*, *Erica arborea*, *Dodonaea angustifolia*, *Rumex nervosus*, *Acacia abyssinica*, *Rhus natalensis*, *Euclea schimperi*, *Accacia etibica*, *Dichrostacys cinearea*, *Calpurnea aurea*, *Rhus vulgaris*, *Podocarpus falcatus*, *Hygenia abyssinica*, *Ekebergia spp.*, *Cardia purpurea*, *Mytenus ovatus*, *Salix substrata* and *Balanite egyptica* (BoANR, 1997).

2.2. Method

Data on fuel-wood (dry-wood and charcoal) were collected for two seasons (dry season/January and rainy season/July) and 7 consecutive days in the pre-identified entry-points (Table 1). Data collected include means of transport (e.g. woman, man, donkey and camel), site of origin, type of fuel-wood (charcoal or dry-wood), species and weight of each load.

Table 1: Fuel-wood monitoring locations and their description

Study town	No. of entry points	Description
Wukro	6	Adimeskel, Endaselasie, Megabit 30, High School, Liyu & Atsbi-road
Mekelle	8	Busines, Adishimdhun, St. Mary's Church, Kebelle-18, St.Gebriel Church (kebelle 17), SOS, Arid & Kelkel-Debri
Maichew	10	Bet-Hintset, College, R. Road, St. Michael Church, Bridge, Police Station, Teklehaymanot (kebelle 01), Hareya, Shemeta & Edaga-Kedam

The collected fuel-wood data were organized and classified to analyze the following major components: i) magnitude/amount of fuel-wood transported to each town; ii) conversion of fuel-wood data to the number of live trees; iii) carbon loss due to forest trees degradation; iv) policy recommendations. Baseline information on forest management, for the pre-war, was obtained from key informants' interview and regional/district offices. The weight of each load transported during the monitoring period was summed-up and divided to the number of monitoring days in each season and town. To estimate the amount of fuel-wood transported during the entire year, a conversion factor of 0.75 (for the dry-season) and 0.25 (for rainy-season) was used. The number of months or days in these seasons is different in that the dry-season represents nine months (October to June) and the rainy-season represents three months (July to September) of the year.

To calculate the total weight of fuel-wood transported, the amount of dry-wood used for charcoal making and the dry-wood directly transported are summed-up (Teka et al., 2017). To quantify the amount (weight) of wood required to produce a given amount of charcoal, a conversion factor of 4.7 (Earl, 1983) was applied. In order to estimate the number of trees cut for fuel-wood, the weight/mass of fuel-wood was first converted to volume using a conversion factor of 1.38 (FAO, 1983), and then to live trees using a conversion factor of 0.56 m^3/tree of 20 cm diameter at base height (Dagnoud et al., 1995). The number or density of trees grown in a given area depends on the potential or carrying capacity of the land (Teka et al., 2017). A land with shallow (<50 cm) and degraded soils has a lower potential to support plant growth. However, an equal size of land with a higher depth (>75 cm) and less degraded is able to grow more plants. This assumption was, therefore, taken into account when estimating the area cleared for fuel-wood. Hence, the forest degradation rate in shallow and deep soils, respectively, was estimated using a conversion factor of 44 ton/ha (FAO, 2006) and 60 ton/ha (WBISPP, 1995) (Eq. 1).

$$DF = Q/Kf \text{ --- } (1)$$

where DF = Deforestation (ha/yr), Q = amount of fuel-wood (ton/yr), Kf = conversion factor (ton/ha)

Carbon dioxide (CO_2) emissions was computed using conversion factors for fuel-wood into CO_2 equivalents (Eq.2) based on the Intergovernmental Panel on Climate Change (IPCC), and the 1996 revised report on Guideline for National Greenhouse Gas Inventory (Baral et al., 2019).

$$\text{Carbon dioxide emission } (CO_2e) = \text{biomass of fuel-wood } (\text{ton.year}^{-1}) * 0.47 \text{ (carbon)} * 3.67 \text{ } (CO_2 \text{ equivalent}) \text{ ---- } (2)$$

Series of meetings with government officials, individuals (forest experts from GOs, NGOs and wood-fuel traders), and others interested in fuel-wood issues were held. Moreover, we critically reviewed both national and regional policies and proclamations as well as scientific literatures on the issue. These meetings and reviews aimed at: i) explaining the actual fuel-wood management practices in Tigray and the studied towns in particular; ii) identifying possible policy changes to improve upon existing approaches to fuel-wood production.

3. Results

3.1. Forest Management and Fuel-Wood use prior to the War

Between 1997 and 2015, different soil and water conservation practices and technologies (e.g. exclosures, gully rehabilitation, tree plantations and hillside terracing) had been introduced on 510,000 hectares of land in the region/Tigray (Gebrehiwot et al., 2022; Teka, 2019). In the same period, 1307 community watersheds were developed (Teka, 2019). Technically, cutting of native species in these areas is not allowed without special cutting permits from the government (BoANR, 1997). Use of non-forest sources such as electricity and kerosene (Teka et al., 2017); agricultural residues or animal dung and fuel-wood imports from neighboring regions appeared to support fuel-wood demand in the region (Teka et al., 2017; Belay, 2007). Furthermore, demand-side programmes focused on the promotion and dissemination of improved wood-burning stoves; while, supply-side programs focused on establishing fuel-wood plantations, especially in peri-urban and fuel-wood deficit areas. For example, 9687.5 kg day^{-1} of *Eucalyptus camaldulensis* entered to Maichew, 3221 kg day^{-1} to Mekelle and 5200 kg day^{-1} to Wukro town from peri-urban areas just before the war broke-out (BoANR, 2019 unpublished report). As a result, the area of afromontane forest increased from 7.2% in 1986 to 18.6% in 2018 (Gebru et al., 2020).

3.2. Fuel-wood Transported to Each Town

The annual average amount of fuel-wood (both dry-wood and charcoal) transported to each of the studied towns (100,000 to 550,000 population) during the war was estimated at 16,055 tones (Table 2). Except for

Eucalyptus, which was collected from farmers' own woodlot around their homestead, the major point source (more than 55% in Maichew and more than 98% in Mekelle and Wukro) was the natural forest or forest reserve (exclosures) within 40 km radius such as the Desea' forest (in the East).

Table 2: Fuel-wood transported to Markets in 2021/22

Study town	Season 1			Season 2			Estimated Fuel-wood (Kg.Y^{-1})
	Dry-wood (Kg.D^{-1})	Charcoal (Kg.D^{-1})	Total Dry-wood (Kg.D^{-1})	Dry-wood (Kg.D^{-1})	Charcoal (Kg.D^{-1})	Total (Kg.D^{-1})	
Wukro	7,006	2,004	16,425	2,908	517	5,340	4,983,685
Mekelle	59,260	13,279	121,671	15,277	800	19,036	35,044,541
Maichew	22,741	1,093	27,878	5,004	110	5,519	8,135,21**6**
Average	**29,669**	**5,459**	**55,325**	**7,730**	**476**	**9,965**	**16,054,481**

Kg = kilogram, D = Day, Y = Year

The number of tree species harvested for dry-wood collection varied between 3 and 19 (Fig.2). In **Maichew town**, only 7 out of the 17 species covered 89% of the incoming dry-wood. The dominant species were, *Eucalyptus camaldulensis* (43%) > *Erica arborea* (19%) > *Dodonaea angustifolia (*9%) > *Rumex nervosus* (8%) > *Acacia abyssinica (*4%) > *Rhus natalensis/Euclea schimperi* (3% each). In **Mekelle city**, only 3 out of the 13 species covered 94% of the incoming dry-wood. These species were represented by *Accacia etibica* (65%) > *Olea europea* (26%) > *Rhus natalensis* (3%). In **Wukro town**, only 2 out of the 3 species (68.6% *Olea europea* and 31.2% *Accacia etibica*) covered 99.8% of the incoming dry-wood.

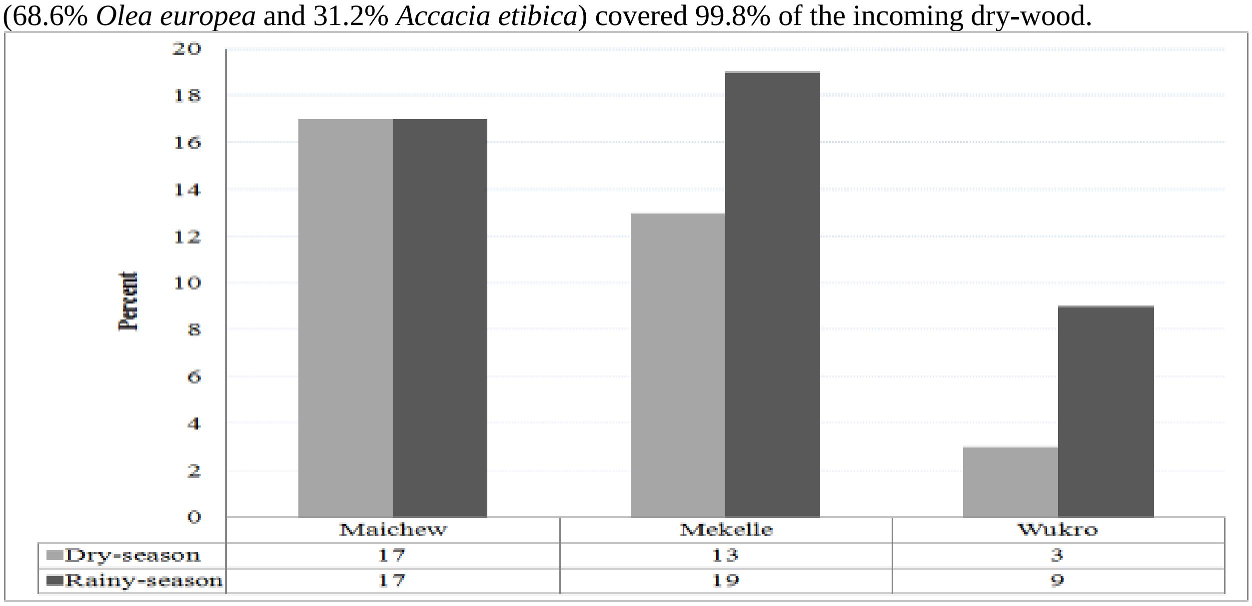

Figure 2. Number of tree species used for dry-wood collection

3.3. Forest Degradation for fuel-wood use

The annual average number of trees cut to deliver fuel-wood to each town before the war was estimated at 39,563, which was much higher than the 5429 trees loss just before the war outbreak. This in turn resulted to disappearance of an equivalent of 268 to 365 hectares of forest annually at the proximity to each studied town (Table 3). Majority of the respondents/farmers' cut live trees 2 or 3 times a week (depending on the occurrence of holidays) and hide them under bushy/denser forests for 2 or more weeks or transport them to nearby villages/houses in order to make them dry.

Table 3: Forest trees harvested for fuel-wood use and transported to the surveyed towns

Study town	Estimated Fuel-wood (ton.Year^{-1})	Volume (m^3.Year^{-1})	No. of trees harvested per year	Deforestation rate (ha.year^{-1})	
				Soils < 50 cm deep	Soils >75 cm deep
Wukro	4,983.7	6,877.5	12,281	113.3	83.1
Mekelle	35,044.5	48,361.5	86,360	796.5	584.1
Maichew	8,135.2	11,226.6	20,047	184.9	135.6
Average	**16,054.5**	**22,155.2**	**39,563**	**364.9**	**267.6**

3.4. CO_2 emissions for fuel-wood use

The illegal tree cutting for fuel-wood resulted in CO_2 – emission of 27,692.4 ton.year^{-1} (Table 4), which is much higher than the 3800.2 ton.year^{-1} just before the war.

Table 4. Carbon loss for fuel-wood use in each surveyed town

Study town	Estimated Fuel-wood (ton.Year^{-1})	CO_2 – emission (ton.Year^{-1})
Wukro	4,983.7	8,596.4
Mekelle	35,044.5	60,448.3
Maichew	8,135.2	14,032.4
Average	**16,054.5**	**27,692.4**

3.5. Identified Policy Recommendations

To overcome the challenges of continuing forest degradation, a set of five future policy recommendations, which have relevance for fuel-wood management in Tigray and the developing world emerged: i) Issuing fuel-wood permits and regulations; ii) Promoting watershed protection and fuel-wood production; iii) Improving fuel-wood management and conversion practices; iv) Emphasizing on market potential of reforestation activities; v) Encouraging and incentivizing alternative energy sources.

4. Discussion

Tens of thousands of hectares of uplands in Tigray have been designated as 'critical watersheds' since 1997, and efforts were underway to replace what are perceived as inappropriate land-use practices with ecologically appropriate reforestation projects. Moreover, to reduce the dependence of energy on natural forest, different non-forest sources were introduced. For example, fuel-wood use from *Eucalyptus* plantations outside the forest reserve prior to the war amount to an annual average of 2203.7 tons per town (BoANR, 2019 unpublished report). This corresponds with the findings in other developing regions that stated trees outside forests meet the bulk of local fuel-wood requirements (Koopmans, 2005; Bhattarai, 2001). Our findings also support the survey results in other developing countries that revealed residents were often responding to forest product scarcities through increased on-farm tree plantation (Rudel et al., 2005). The overall result was a threefold increase, from 7.2% in 1986 to 18.6% in 2018, in the area of afromontane forest (Gebru et al., 2020).

The annual average amount of fuel-wood transported to each of the studied town, during the war, was 628.7% higher than the amount transported just before the war outbreak. This is much higher than the estimated amount for Goma city of Democratic Republic of Congo (about half million population) that consumed an estimated 2,947 tons of charcoal and 3,926 cubic meters of wood (Emily, 2010). Unlike to the pre- war outbreak, the major fuel-wood source during the war was the natural forest or forest reserve (exclosures). This also corresponds with the findings for South-Eastern Ethiopia that revealed about 83% of the respondents collected fuel-wood from forest reserves (Mohammed et al., 2020).

As stated in Figure 2, the number of tree species harvested for dry-wood collection varied between 3 and 19 depending on the agro-ecology and proximity to the natural forest. These findings are in par with the household level common species consumption study results for urban areas of Tigray including the study districts (Teka et al., 2017). These authors revealed that *Olea europaea* (68.6%) in Wukro town, *Acacia etibica* (51.5%) in Mekelle city and *Eucalyptus camaldulensis* (40.8%) in Maichew town were the dominant species used for fuel-wood. Other studies also found out that the most exploited tree species in the remnant dry afromontane forests were *Juniperus procera*, *Olea europea, Podocarpus falcatus* and *Hygenia abyssinica* (Mohammed et al., 2020; Zenebe et al., 2020).

The war in Tigray has also resulted to an annual loss of extra 5429 trees as compared to the pre-war. In line to our findings, estimates for the Virunga National Park of Goma city in Democratic Republic of Congo revealed that at least 432 to 576 hectares of tropical forest disappear every month (Emily, 2010). The tree harvesting method was total felling/total destruction. A similar result was also reported for South-Eastern Ethiopia and other developing countries that revealed more than 83% of the respondents collected fuel-wood by cutting live trees (Mohammed et al., 2020; Asian-Development-Bank, 1995).

The illegal tree cutting for fuel-wood, in the study area during the war, resulted in a 3800.2 $ton.year^{-1}$ higher CO_2 – emission compared to the pre-war. This corresponds with the interview results from 217 households in Kankali community managed forest of Nepal that revealed 60% of the households who depend on fuel-wood for cooking apparently emit approximately 13.68 tons of carbon dioxide annually (Baral et al., 2019). Other studies also showed that total distraction of a single tropical tree can lead to an annual loss of 22.6 kg or 2.5–3.6 $ton.ha^{-1}$ of carbon dioxide (World-Agroforestry-Center, 2011).

Hence, the following five sets of policy recommendations were identified, from experts' judgment and review documents, to overcome the challenges of continuing forest degradation:

i) **Issuing fuel-wood permits and regulations:** producing, packaging, transporting and trading fuel-wood and charcoal can employ large number of people and earn revenues for the government or other resource owners. For example, in Dareselaam and Malawi, the fuel-wood and charcoal trade involves 125,000 and 92,800 people, respectively (World-Agroforestry-Center, 2009). Hence, issuing fuel-wood permits and regulations can play a pivotal role in the sustainable utilization of forest resources. The most commonly used forest management regulations worldwide are: private land-owners can cut planted trees on their own land without a permit, but they must apply for a transport permit if they want to sell any of the wood from these trees somewhere else; special cutting and transport permits are required if a landowner wants to cut naturally growing tree species found on his/her lands (Bensel, 2008); there should be a binding rule for permitted or legal fuel-wood suppliers (Parviainen et al., 2009); a certified site must have a minimum of 5–10 trees per hectare (Parviainen et al., 2009); where stump extraction is permitted, at least 30% on stumps shall not be harvested (Kankaanpaa et al., 2005); for ensuring biodiversity, at least 5 $m^3.ha^{-1}$ of dead wood shall be left on the regeneration site (Kankaanpaa et al., 2005); the landless should be given seedlings provided free of charge and given ownership of trees in return for their guarding and watering the seedlings (Bensel, 2008).

ii) **Promoting watershed protection and fuel-wood production:** many of the towns in Tigray region are laid in a location surrounded by mountainous topography which is exposed to flooding (Teka et al., 2017). To minimize the effects of flooding and at the same time fulfilling the fuel-wood demand of their population, realization of urban watershed is a proved approach (Parviainen et al., 2009). The "analysis of household's energy consumption, forest degradation and plantation requirements" study for the eastern Tigray in 2017 recommended an estimated annual tree plantation of area ranging from 286 ha around Maichew town to 21,684 ha around Mekelle city (Teka et al., 2017). Hence, planting suitable tree species on cultivated lands, strip lands (e.g. farm bunds and boundaries, roads, canals and drains), degraded forest lands and uncultivated degraded lands (non-forest and non-cultivated lands) can help supply fuel-wood to the urban poor (Saxena, 1997). For example, half of the fire wood burned in Thailand, more than three-quarters in Indonosia, Java, Pakistan & Vietnam, and four-fifth in India is cut from farm land and other non-forest areas (World-Agroforestry-Center, 2011). For household usage, families should be encouraged to plant a mix of fast growing and multiuse trees on their homesteads so as to diversify income sources, overcome potential problems from pest or disease infestations and increase biodiversity in addition to securing their energy sources (Bensel, 2008).

iii) **Improving fuel-wood management and conversion practices:** fuel-wood burning in many developing countries including the study area is done on less efficient energy conversion traditional stoves (Manaye et al., 2020; Dresen et al., 2014; Gulilat et al., 2011; Shanko and Lakew, 2011; Bensel, 2008; Feleke, 2007). The energy conversion efficiency of these stoves ranges between 10.2 and 19% (Bhattacharya and Salam, 2002) compared to the 40% fuel-wood savings by improved cooking stoves (Manaye et al., 2020; Dresen et al., 2014). These in turn led to a total GHG emission of about 110 g of CO_2 equivalent per mega joule of useful energy compared with 42 g for improved wood-stoves and 5 g for biogas (Bhattacharya and Salam, 2002). Hence, application of fuel-wood use saving mechanisms can help reduce the burden on natural forest and thereby reduce carbon emission. The use of improved cooking stoves results in 0.65 tons of carbon dioxide equivalents (CO_2e) emission reduction per stove per year (Manaye et al., 2020).

iv) **Encouraging and incentivizing alternative energy sources:** any sustainable development solution in the household energy sub-sector must focus on renewable energy sources (e.g. Biogas, Bio-fuels, Wind, Solar and Hydro-power). For instance, **Biogas** stoves have conversion efficiency of 55% (Bhattacharya and Salam, 2002). A biogas technology, having 8 m^3 digester size, can save about 1423 kg of fuel-wood with an emission reduction potential of 2.1 tons of CO_2e per biogas plant (Desta et al., 2020; Dresen et al., 2014). Growing **Bio-fuels** (e.g. Jatropha and sweet sorghum) can also help alleviate energy shortages, sequester carbon and improve incomes (World-Agroforestry-Center, 2009). **Wood residues** generated during harvesting and processing is another alternative energy source. For example, wood residues fulfilled the Cameroon's total electricity demand of 3,320 Gigawat-hours, 60% of the electricity consumed in Gabon and 12% in Nigeria (World-Agroforestry-Center, 2009). Similarly, **energy** from hydro-, solar or wind power is a good substitute for fuel-wood that is harvested unsustainably (Owusu and Asumadu-Sarkodie, 2016; Kaunda et al., 2012; Panwar et al., 2011).

v) **Emphasizing on market potential of reforestation activities:** Many reforestation and conservation projects continue to promote tree planting primarily for ecological reasons (Murray and Bannister, 2004). However, studies suggested that the most promising approach is enabling local communities and farmers to rehabilitate and manage forest lands and directly benefit from their efforts (Chokkalingam et al., 2006). These can be achieved if and only if they provide market opportunities. Farmers and landowners are more likely to undertake tree planting and management when these are perceived to provide market opportunities (Murray and Bannister, 2004; Russell and Franzel, 2004; Scherr, 2004).

5. Conclusions

In view of the limited access to electricity and kerosene, due to the existing war and siege, most households in Tigray excessively depend on fuel-wood. The study results indicated that the annual average amount of fuel-wood transported to each of the studied towns was 16,055 tones, which is by 628.7% higher than the amount transported just before the war outbreak. The number of tree species cut for the purpose ranges from 3 in Wukro town to 19 in Mekelle city. The resulting annual average number of trees cut to deliver fuel-wood to each town was estimated at 39,563 trees, which was much higher than the 5429 trees loss just before the war. Hence, an equivalent amount of 268 to 365 hectares of forest at the proximity to each studied town disappeared every year. These in turn resulted in an average CO_2 emission of 27692.4 ton.year^{-1}, and a seven fold increase compared to the situation before the war outbreak. It can, therefore, be concluded that the high dependency of the community on Fuel-wood resulted to a high forest degradation and carbon loss. Hence, the following policy recommendations, which have relevance for fuel-wood management in Tigray and the developing world, are suggested: i) Issuing fuel-wood permits and regulations; ii) Promoting watershed protection and fuel-wood production; iii) Improving fuel-wood management and conversion practices; iv) Emphasizing on market potential of reforestation activities; v) Encouraging and incentivizing alternative energy sources.

Acknowledgments
The author would like to thank the authorities of the studied towns for their technical support during monitoring data collection.

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