




## Article

# Charcoal and Wood Biomass Utilization in Uganda: The Socioeconomic and Environmental Dynamics and Implications

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**Abstract:** Charcoal and firewood fuel biomass utilization is thought to be the main cause of deforestation in Uganda. Moreover, the practice of utilizing charcoal and wood fuel in Uganda is said to impact the health of many women and children in the region. The goal of this study was to comprehensively analyze charcoal and wood fuel utilization processes in Uganda and sub-Saharan Africa and the environmental and socioeconomic dynamics and implications. The study equally intended to model out some possible improvements to wood fuel use while conserving natural forests. Both qualitative and quantitative approaches were used to study the charcoal and wood fuel energy situation in Uganda. The study collected field data (sample size: 199) which was subjected to descriptive analysis. The findings show that over 90% of households in Uganda and the sub-Saharan region use firewood and charcoal wood fuel, and that this fuel use creates social and environmental hazards. Our findings are also in agreement with numerous empirical studies showing that firewood and charcoal biomass are among the major causes of deforestation in Uganda and the sub-Saharan region. *Ceteris paribus*, we propose the adoption of Improved Eco-Stoves (ICE), which not only enable comprehensive combustion but also lessen the quantity of firewood used by more than 60%, together with policy decisions on the government of Uganda, given peoples willingness to take on alternative energy sources such as gas and electricity.

**Keywords:** biomass; charcoal; deforestation; economy; energy; health; innovations; livelihood; women

## 1. Introduction

Uganda is a nation well-endowed with natural/virgin forests of various species of the famous African hardwood. While these forests mainly support biodiversity and the entire forest ecosystem, they also contribute to the national Gross Domestic Product through wood production and trade and eco-tourism [1–3].

Uganda, like most other sub-Saharan African countries, heavily relies on biomass as an energy source [1,4,5]. Given the fact that the Ugandan population does not have nationwide access to modern

energy sources, the resulting tendency is to over-rely on and consume wood biomass [1,6,7]. Due to the lack of modern alternatives, charcoal is a highly consumed form of biomass in Uganda [1,2,4,5]. Both in the cities, urban centers, and the villages, charcoal and wood fuel seem to be not only an economic activity for the majority of women but also a source of livelihood for participating women and households in the charcoal business especially [1–3].

The demand for biomass in tropical regions of sub-Saharan Africa, particularly fuelwood, is projected to grow exponentially in the future [8]. Wood fuel, such as charcoal or firewood, is the most common form of biomass utilized in sub-Saharan African countries [8,9]. Sassen et al. [8] further revealed the effect of biomass use on forest development by showing that forests would plunge into degradation because of cutting down trees for firewood or charcoal for household use.

It is of the utmost importance to immediately obtain information on the dynamics between biomass production and deforestation to further elucidate the state of deforestation in Uganda and provide remedial solutions.

This is also exacerbated by poor methods of wood fuel use, such as the use of old traditional cookstoves (Figure 1B), and an outdated process for making charcoal (Figure 1A,C). The charcoal is packed in sacks and loaded onto trucks to be transported to mostly urban areas (Figure 1D). Logging for charcoal and firewood production is thought to be the most direct underlying driver of deforestation and forest degradation in Uganda [1,4,5]. As much as charcoal and wood are sought to form the socioeconomic muscle of many households, they are also sought as a major driving factor of deforestation and forest degradation in the region.



**Figure 1.** Charcoal production and firewood biomass. Source: Bamwesigye et al. [1].

Equally important is that biomass combustion produces smoke that may influence the reproductive health outcomes of women [10]. Women who use biomass fuel, such as firewood for cooking, are at high risk of developing reproductive difficulties. As such, it is imperative to develop solutions and approaches that would help to reduce the emission of dangerous biomass fumes following combustion in a bid to safeguard public health. Ultimately, a collective effort must be made to improve our understanding of the effect that partaking in biomass use has on women and children's health. This must be coupled with the careful introduction of sustainable policies that reduce the exposure of women and children to biomass smoke emissions [10].

To achieve the study objectives, both qualitative and quantitative methods were used [11–13]. These included a literature review and content analysis, primary and secondary data collection and descriptive analysis.

The goal of this paper is to explore charcoal and firewood/wood fuel biomass use in Uganda. The socioeconomic and environmental implications are critically studied herein.

*Ceteris paribus*, understanding the socioeconomic and environmental dynamics and implications surrounding charcoal and wood fuel in Uganda is of paramount importance as far as policy decisions are concerned. This paper is a perfect addition to the board of knowledge concerning reducing forest degradation and deforestation. Also, this study contributes to possible solutions to the problem of poor biomass use in Uganda and the region.

## 2. Literature Review

Hood et al. [14] defined biomass as any organic matter that in one way or another can be renewed over time. In simple terms, biomass is about the storage of energy. Similarly, Malinen et al. [15] explores woody biomass and defines it as the accumulation of biomass, such as the roots, wood, and leaves of a tree, above and below the ground. The author explains that such biomass can be used for power generation, heat generation, biofuel production, biochemical production, and electricity generation. Monroe [16] adds that wood residues, wood by-products, fast-growing trees, bushes, and shrubs are all considered to be sources of woody biomass.

During the photosynthesis process, plants use light energy (energy from the sun) to convert carbon dioxide and water into simple sugars and oxygen. Moreover, Hood et al. [14] points out that fossil fuels are usually hydrocarbon deposits, which may include natural gas, coal, and petroleum, that derive from organic matter, especially from previous geologic periods. These are referred to as 'fossilized biomass', and they differ from present-day biomass. On the same note, Malinen et al. [15] explains that biomass absorbs carbon from the atmosphere as it grows and returns it to the atmosphere, especially after it has been consumed. In fact, this usually happens in a relatively short period of time. From this perspective, it is worth mentioning that biomass utilization usually creates a closed-loop carbon cycle.

An example is that one can grow a tree in a period of ten years, cut it down, and then burn it, which allows for the release of its carbon back into the atmosphere. In the case of the fastest-growing biomass crops, such as switchgrass, this process usually occurs at a faster rate than one can even imagine. Interestingly, Vlosky and Smithhart [17] notes that more biomass resources than ever before are being converted to energy using different processes to generate electricity, fuel vehicles, and provide heat, to mention but a few applications.

Policymakers, energy producers, and developers across the globe continue to search for better and, at the same time, less expensive, more reliable, and renewable domestic sources of energy. Biomass is one of the best available alternatives because it is less expensive, clean, and currently the only renewable source of liquid fuel for transportation [17]. Similarly, Hatfield [18] speculates that renewable resources are the key ingredient in a sustainable future for this planet. In fact, renewable resources such as biomass play a significant role, in terms of scientific approaches, in the process of finding solutions to current energy problems. According to Renström [19], biomass started to be a solution to energy

challenges as early as the 1970s. In other words, it is not surprising that biomass has become one of the best renewable resources for both small and large-scale consumers.

While biomass currently supplies more than 14% of the energy the world consumes, Hatfield [18] highlights that more than three-quarters of the world's population live in developing countries, and that is where biomass is needed the most. With the current increase in the population as well as the per capita demand, biomass utilization is expected to rapidly increase, especially in developing countries. On average, biomass has been used to produce more than 35% of the total primary energy in various developing nations. However, in some countries, that value has risen to 90%. From this perspective, it is worth mentioning that biomass is expected to become the core source of energy in developing countries [17].

According to Hood et al. [14], if biomass energy is appropriately managed, it has the potential to be sustainable in various countries. In addition, it usually creates jobs for local people, which, in turn, improves the health of the population. Moreover, a wide range of studies have shown that biomass has also been recognized in developed or industrialized countries, including the United States, Mexico, and Japan [20,21]. For example, biomass utilization was first incorporated into Japan's Basic Act strategy in 2002, and it was later emphasized in 2009 [22]. In the Basic Act, the national government of Japan lists measures that are essential to realizing the utilization of biomass. Some of these measures include laying the necessary groundwork for biomass utilization through the creation of projects that supply biomass products.

In Turkey, Melikoglu [23] highlights that the country's vision for 2023 focuses on having an installed capacity of biomass power plant that is about 2000 MW. In fact, Turkey has recently spent millions of U.S. dollars in a bid to fulfill its biomass energy vision of 2023. In other words, the country is making massive investments in the setting up of biomass power plants, which will help it to reduce its trade deficit, especially in terms of importing energy sources. However, most countries including Turkey have limited biomass resources with which to fulfill their visions [24,25]. It is not surprising that international trade in biomass has increased in recent years.

In the United States, the government continues to work hard to support policies for and investment in biomass installations. In fact, Carleton [26] highlights that the United States, like never before, is aiming to diversify its energy matrix in one way or another. The country has recently invested more than 22 million dollars in technology in a bid to become one of the leading nations in marine biomass [26]. In this case, it is worth mentioning that this investment aims to achieve efficiency, especially in the transformation process.

According to Wolfsmayr and Rauch [27], forest biomass that is used in electricity, biofuel, and heat generation has become a core area for the United States. Some states, such as Minnesota, are using appropriate scales and technology to increase their production of energy from biomass. Moreover, Carleton [26] mentions that the United States' Energy Information Administration (EIA) estimated that Minnesota's biomass consumption is 8.7%. This percentage is higher than that of nuclear power and more than half that of coal. Still, in 2007, the state of Minnesota enacted the Next Generation Energy Act, which requires an increase in the use of renewable energy to reduce carbon emissions. As a result, biomass has become the major alternative source of energy.

Studies show that many countries have started to draft renewable energy laws with the aim of supporting strategies to increase energy supply. For example, Hood et al. [14] speculates that China is a leading country with a large amount of biomass energy resources, especially in rural areas. Moreover, China is currently producing a wide range of raw materials and, at the same time, discouraging the use of non-renewable energy to make its economy sustainable and clean [24]. Advances in technology have helped China to increase its total annual production of biomass. In 2008, for example, China constructed more than 100 plants, which accounted for at least 7% of the total biomass production in the country [24,25].

In Bangladesh, there has been an increase in energy consumption and the country is focusing on renewable energy sources including biomass [28]. Some materials such as wood, agricultural residues,



and municipal waste are being used to increase the production of biomass. However, production in Bangladesh has been limited by feedstock.

Since 2008, the United Kingdom has placed much focus on renewable energy sources, such as biomass, to increase its energy production. According to Vlosky and Smithhart [17], the United Kingdom has invested more than 600 million dollars to build a biomass plant with an installed capacity of 299 MW. In fact, research indicates that the United Kingdom has consistently supported renewable energy systems and fostered technological advancements to increase biomass production by 30% by 2030 [29]. In this case, it is not surprising that setting up one of the largest biomass plants in the port of Teesside has the potential to help mitigate climate change while increasing renewable energy production.

The smoke released from burning firewood is of a unique composition. It consists of most air pollutants and factors to which consistent exposure can put human health at risk [30]. In many firewood-reliant communities, women and children take responsibility for collecting and transporting firewood. The collected firewood biomass is transported in the most primitive ways; commonly, women and children carry it on their heads [31]. Das et al [32] states that biomass fuels are the predominant form of energy in firewood-dependent regions of sub-Saharan Africa, accounting for over 90% of household energy consumption. Similarly, it is the cultural responsibility of women and children to cook meals; therefore, they are predominantly exposed to the adverse impacts of firewood biomass use. Furthermore, over one-third of the day is spent shuffling between collecting and transporting firewood. This results in the occurrence of prolonged fatigue in these children and women [32].

As such, the consequences of continued exposure to and inhalation of smoke from burning firewood include health complications through indoor pollution by the dangerous gases that are released from burning firewood when cooking [33]. Additionally, emissions from biomass combustion negatively affect both the respiratory and the cardiovascular system [34]. Correspondingly, Das et al [32] found that women who used firewood when cooking stated that they had difficulty with breathing, chest pains, night phlegm, dizziness, and dry irritated eyes. Biomass fuels particularly those from firewood, have had dreadful impacts on the respiratory health of women in Nigeria. In fact, the author observed that symptoms compromising the respiratory system occurred more frequently amongst these women compared with the control group. The respiratory symptoms observed in the women were a cough and phlegm with a higher incidence of airway obstruction [35].

Moreover, domestic cooking with biomass fuels exposes women and children to pollutants that impair health [36]. On the same note, the authors observed that women and children who cooked using firewood reported cases of household air pollution and continued occurrences of compromised lung health. In the study conducted by Oluwole et al. [36] on the use of low-emission stoves, the authors found significant reductions in the frequency of respiratory symptoms, such as a dry cough, suffocation, and runny noses, in mothers and children. In fact, these stoves were found to have efficiently enhanced the indoor and household air quality through reducing the exposure of women and children to dangerous pollutants. Similarly, the results of an investigation conducted by Schilman et al. [30] indicate that children belonging to households that used a Patsari stove had lower rates of respiratory infection compared with households that used open firewood.

Wood fuel such as charcoal or firewood is the most common form of biomass utilized in sub-Saharan African countries [9]. Sub-Saharan African nations of Burundi, Burkina Faso, Central African Republic, Chad, Gambia, Liberia, Rwanda, Uganda, and Sierra Leone have over 90% of their population said to be reliant on woody biomass energy [37]. Charcoal is mostly utilized in urban areas of the region, whereas firewood is predominantly consumed in rural areas of the region [37–40]. Jones et al [40] found that in sub-Saharan Africa, four out of five people conventionally rely on solid biomass, primarily fuelwood for cooking, which makes it a source of food security.

Jones et al [40] further state that tropical wetland ecosystems are uncommon but similarly highly utilized sources of biomass. Papyrus is the emerging form of biomass from these wetlands due to the

high primary productivity rate, which ranges between 25.9 and 136.4 tDM ha<sup>−1</sup> yr<sup>−1</sup>. Papyrus is most utilized by stack-weaving it into Papyrus mats. Furthermore, Jones et al [40] reveal that the biofuel properties of Papyrus can be exploited by converting it into compressed or carbonized briquettes for cooking. Briquette-making is a popular technology that has been adopted in sub-Saharan Africa to fully utilize biomass through conversion into biofuel [41]. Moreover, biofuels are efficient and combustible sources of energy that are produced from biomass [42]. Biomass briquetting is among the numerous ways that bulky low-density biomass can be converted into high-energy fuel for cooking and sometimes heating [43]. This form of energy has been purposely adopted as an alternative form of energy to potentially reduce the dependence of sub-Saharan African countries on firewood and charcoal [40,42,43].

Studying the effect of biomass on the health of sub-Saharan African women provided interesting results. Cultural law mandates that women in most African countries are responsible for collecting wood biomass for domestic use. This has serious implications given that Das et al [32] found that biomass fuels account for approximately 90% of household energy consumption. From this perspective, there is a correlation between women's health and biomass utilization in Sub-Saharan Africa. In most cases, women from rural areas in the sub-Saharan African region are burdened with heavy workloads as they are mandated to collect firewood from nearby or surrounding forests. Moreover, a common misconception in rural sub-Saharan Africa is that firewood is free and, as such, its collection is guaranteed. Das et al [32] also observed that the use of firewood and crop residue, when compared with the use of charcoal, was a factor in a higher incidence of difficulties with breathing, chest pain, night phlegm, loss of memory, dizziness, and dry irritated eyes.

### 3. Materials and Methods

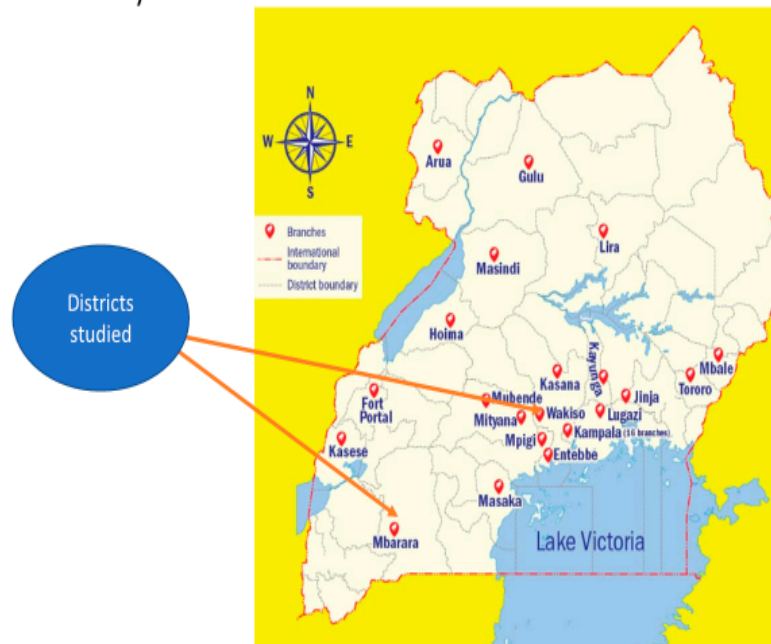
The country under study is Uganda. Uganda is a landlocked country in East Africa. The country is endowed with natural and evergreen forests and vegetation. However, the amount of this vegetation has reduced over time, which motivated us to analyze what role charcoal and firewood have played in this reduction of vegetation that many people depend on.

Our study used both qualitative and quantitative approaches as described by Creswell [11]. Qualitative research techniques are used in ethnography, narrative research, phenomenology, exploration, and case studies. In our study, we used exploratory techniques, photographs, literature, and content analysis [12,13]. Additionally, quantitative data were studied and analyzed to understand the trends in charcoal and wood fuel production as well as household charcoal use in Uganda.

The investigation employed a content analysis approach to analyze charcoal and wood biomass utilization in Uganda and the sub-Saharan region. Content analysis is one of the best research methods for studying and analyzing a range of textual data, thus, attaining valid and replicable propositions [13]. It is a technique for examining written, verbal, and visual communication data. We explored various scientific materials, data bases, web pages, and reports. The selected materials concerned charcoal, wood fuel or biomass, and or deforestation. Materials about Uganda were given priority, however the study also consulted similar studies related to the topic of study that are in line with the study's goal.

We used materials from major scientific databases, reports, and web pages including The Food and Agriculture Organization of the United Nations (FAOSTAT: Appendix B) and Global Forest Watch. Our main source of data was secondary data, and we studied a lot of literature to come up with an output. We used the Google Scholar, SCOPUS, and Web of Science databases to obtain resources and materials. The photographs in Figures 1 and 2 speak volumes on the entire value chain for both charcoal and firewood, their use, and a few of the visible impacts, such as deforestation [1]. Some of the photos were taken by the author. The internet searches were focused on some key words, charcoal, Uganda, biomass, wood fuel, firewood, and deforestation. Also, forest loss was studied in line with deforestation.

## Study Areas: Mbarara and Wakiso Districts in Uganda



**Figure 2.** Location of study sites (Mbarara and Wakiso Districts) in Uganda.

This research examines the use of wood biomass in sub-Saharan Africa in general and Uganda in particular, its impact on the deforestation process, and its impact on the health of women and children. We also propose alternatives for the purpose of reducing the impact of biomass use on deforestation and the health of women and children.

The study attempts to answer the following questions:

- What is the charcoal and biomass use situation in Uganda and the sub-Saharan African region?
- What are the socioeconomic and environmental impacts of charcoal and biomass use in Uganda?

The primary research section attempted to find out the extent of charcoal and wood fuel in general (Tables A1–A6). In Uganda where most people use charcoal in the urban areas and a mixture of charcoal and firewood in the rural, part of the bigger study which is part of the Ph.D. dissertation asked about this charcoal and firewood use.

The data were collected from Mbarara and Wakiso Districts from December 2018 to March 2019, these places were designated for a primary research study (Figure 2). Wakiso District is in the central region of Uganda in the outskirts of Kampala the Capital City. The district is estimated to have a population of about 2 million people and about 1942.49 sq km of land.

Whereas Mbarara District and city is the main city in the western region of Uganda with a population of about 500,000 people, and covering the size of about 1812.99 sq km. The geographic location of the investigated Districts; Mbarara ( $0^{\circ}20'43.7''$  S  $31^{\circ}33'01.8''$  E) and Wakiso ( $0^{\circ}24'20.6''$  N  $32^{\circ}28'17.4''$  E) coordinates. A coordinate system enables every location on Earth to be identified by a set of numbers. A mutual choice of coordinates is latitude and longitude.

The questionnaire included four sections, the first was concerned with biodata of the respondents, the second with governance issues and deforestation, second knowledge of forest functions, and charcoal/firewood use, among other sections including policy issues given the deforestation situation in Uganda.

Some of the questions included:

1. Do you use wood fuel (charcoal or firewood) materials in your households?

(1). Yes

- (2). No
2. What estimated value would you give wood fuel (charcoal or firewood) used in your household monthly in Ugandan Shillings (UGX)?
- (1). Less than UGX 10,000
  - (2). UGX 11,000–20,000
  - (3). UGX 21,000–30,000
  - (4). UGX 31,000–40,000
  - (5). UGX 41,000–50,000
  - (6). UGX 51,000–100,000
  - (7). More than 100,000
3. Which alternative source of energy would you be willing to pay for if subsidized to change from firewood/charcoal use?
- (1). Gas
  - (2). Hydroelectricity
  - (3). Biogas
  - (4). Others

A simple probability sampling was used to get respondents for interviews given the quantitative nature of the study. This was due to a quick and inexpensive approach. Each member of the population had equal chances of being selected and participated in the study. The studied villages all together have a population of about 2500 households. The study interviewed 203 household respondents who were comprised of approximately 8% of the studied population.

The collected data were subjected to descriptive analysis where frequency tables were generated to understand the proportionalities for both biodata and charcoal and or firewood use at household level. Additionally, an analysis of possible energy alternatives was conducted.

## 4. Results and Discussion

### 4.1. Socioeconomic Dynamics and Implications

Our results from the primary research illustrated that about 92% answered yes, and 8% no for the use of charcoal/ wood fuels. Hence showing that most of the households of the respondents use charcoal or wood (Table A1). The household charcoal use was also assessed by the value households spend on it monthly. 21% spend Ugandan Shillings 10,000, 14% between Ugandan Shillings 10,000 to 20,000, 19% between Ugandan Shillings 20,000 to 30,000, 20% between Ugandan Shillings 30,000 to 40,000, 11% between Ugandan Shillings 40,000 to 50,000, 11% between Ugandan Shillings 50,000 to 100,000, and 6% for Ugandan Shillings 100,000 and more (Table A3).

Charcoal doubles also as a source of income for numerous households especially the women who sell retail as well as small enterprises [1,2]. Many women in Uganda can put food on the table because of the incomes they gain from the trade of charcoal as a commodity [2,38]. Charcoal and wood fuels in Uganda are the engine of “Food water and energy nexus”. Even though it plays a critical role for the urban poor, also the rich use still it, given the limited supply and expenses on electricity as well as gas [1,2,38]. This can be evidently observed in the scores of charcoal use for both urban and rural (Table A2). These results did not show any differences on the factors that could affect the use of charcoal and or firewood such as sex of respondents, household incomes, and or residence (Tables A2, A4 and A5).

However, traders in the charcoal business were worried about their livelihood since charcoal is their main source of income. They nevertheless too think that their business is responsible for escalating deforestation and climate change in the country, which is not in line with previous studies [1,2,38].



Energy utilization is a fundamental requirement for economic development and a general trend observed on a global scale. As such, there must exist a form of sustainable energy consumption in both rural and urban settings to promote this economic growth. However, this can be rather difficult for some African countries, particularly those in the sub-Saharan African region. It goes without saying that this region is constricted as far as access to modern energy is concerned. In this case, there is a tendency to overtly exert pressure to consume biomass in the case of Africa [6]. In fact, sub-Saharan Africa is among one of the most underdeveloped regions in the world. Its energy needs are satisfied through the utilization of readily available biomass.

Essentially, biomass is an energy source provided by nature to meet inexhaustible energy demands [37]. Da Silva [38] briefly describes biomass as a form of organic matter that is renewable and free to use as a renewable energy resource. Furthermore, the authors also stress that the energy aspect of biomass is exploited through both direct and indirect means. Da Silva [38] states that the former is achieved through combustion to produce heat while the latter is achieved after conversion into various forms of semi-processed biofuels. In several countries in Africa, biomass is used entirely for heating and cooking [39].

In the case of sub-Saharan Africa, the most utilized form of biomass and energy, in general, is wood based, which makes this form of biomass the basis of energy production in the region. Biomass comprises all organic matter that self-replenishes over time. It is not limited only to woody mass. However, woody mass is Africa's primarily utilized form of biomass. In general, about 80% of Africa's energy consumption is in the form of woody biomass. Over 81% of the sub-Saharan African population source energy from woody biomass, which is entirely used for cooking and is a higher rate than anywhere else in the world [37].

The culture in Uganda and many other developing nations is that it is the responsibility of women and children to collect and transport firewood [31]. Consequently, this exposes them to physical harm and associated health complications. In addition, there is a high risk of health complications arising from continued exposure to indoor air pollution and inhalation of dangerous gases during cooking with charcoal and firewood [33]. Furthermore, Owili et al. [44] observed that continued use of charcoal and biomass was linked with a high risk of mortality in children under five years of age in Sub-Saharan Africa. Awopeju et al. [35] in Nigeria provided evidence of the adverse effects that biomass fuels had on the respiratory systems of women who cooked on the streets using biomass fuels. The authors found that there were higher chances of respiratory symptoms amongst these women compared with a control group. The most observed symptoms were a cough and phlegm with a higher incidence of airway obstruction.

#### *4.2. Environmental Dynamics and Implications*

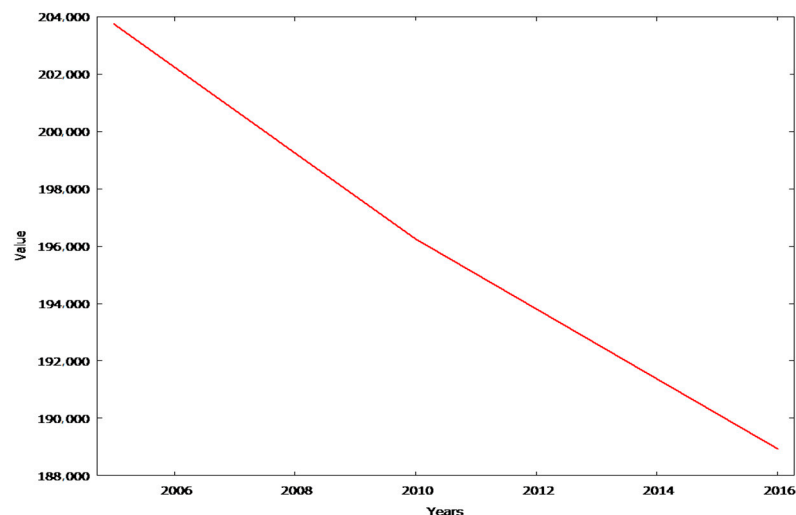
Exploring the relationship between biomass use and deforestation also provided interesting results. The supply of biomass in sub-Saharan Africa is derived from forests; therefore, deforestation may limit biomass supply in the future. Jagger and Kittner [45] found that deforestation does indeed jeopardize the food security of and the supply of biomass to the forest-dependent population of Uganda. However, the same report found that households usually opted to source biomass, such as fuelwood, from low-quality and scarcely supplied forest areas. In this case, this correlation does indeed speak volumes about the actual threat that deforestation poses to the stability and sustainability of sub-Saharan Africa's biomass base.

A popular assumption is that private tree plantation would be able to provide alternative biomass sources of high quality to natural forests; however, Jagger and Kittner [45] revealed that this was indeed not the case in sub-Saharan Africa. Similarly, Cazzolla et al. [46] stated that uncontrolled logging will greatly damage the process by reducing the amount of biomass that tropical forests produce in the future. Forest land cover has declined sharply (Figure 3) for decades in the East African region, particularly during the period 2005–2017. On the other hand, the produced quantities of wood fuel, round wood, and industrial wood have significantly increased compared with charcoal (Figures 4–6).

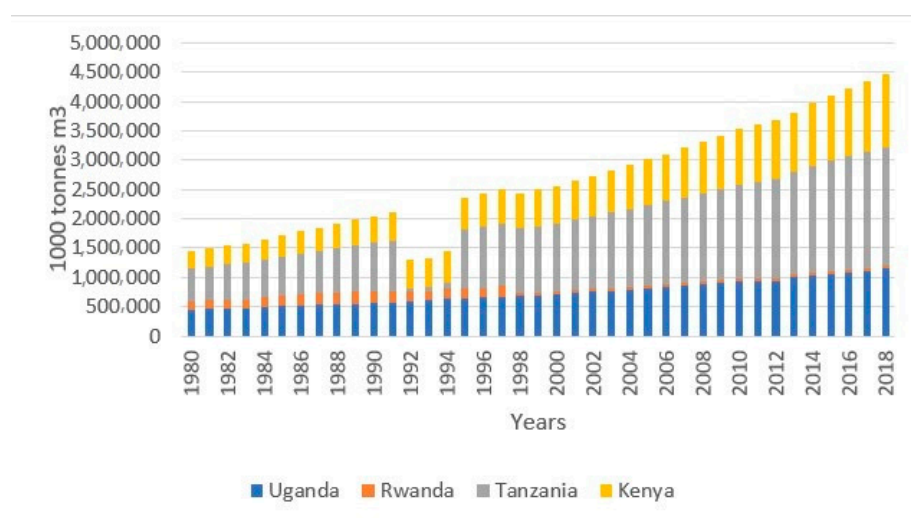
Studies show that this increase averages over 15% per year, with an increase of up to 25% in some years, particularly for wood fuel/charcoal [1,38–46].

We compared the wood production trends for the period 1980–2018 by means of a trend analysis of production quantities in Uganda, Kenya, Tanzania, and Rwanda (Figures 4–6) of:

- Charcoal, wood fuel, and round wood.

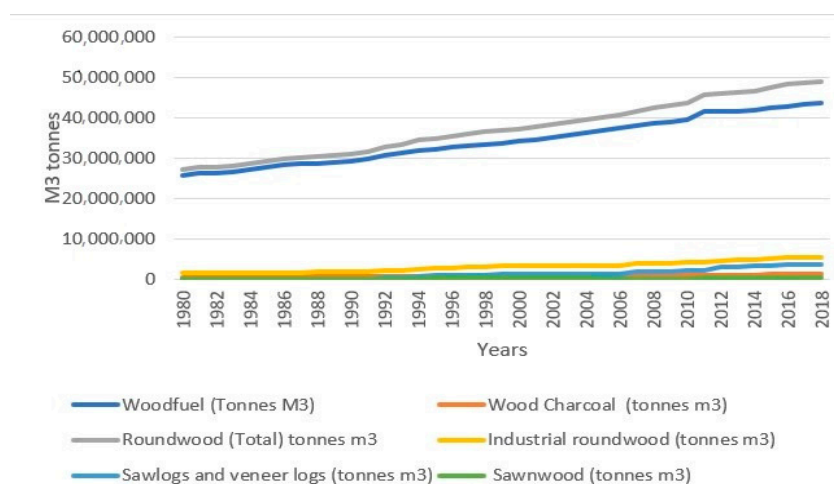


**Figure 3.** The trend in forest land cover changes in Uganda (1000 ha) (2005 to 2017). Source: Authors' Analysis using gretl.

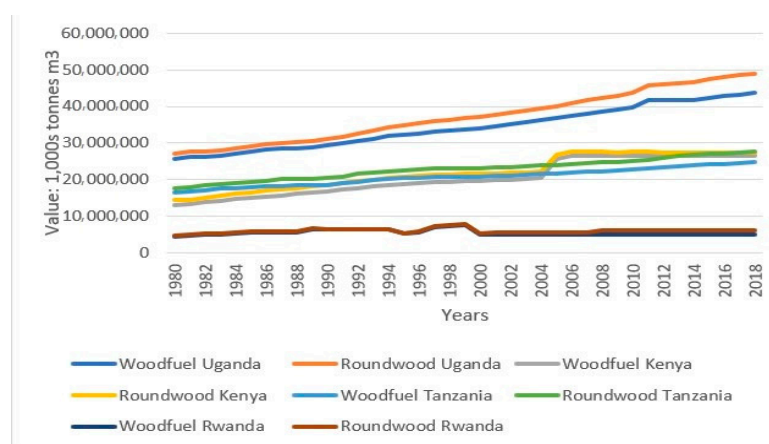


**Figure 4.** Analysis of charcoal production quantities (1000 tonnes) over time (1980 to 2018) in Uganda, Kenya, Tanzania, and Rwanda.

The trend presents a very significant positive increase for the three products, with charcoal and round wood having sharp slopes across five decades (Figures 4–6 and Table A7). The trend in forest land cover loss in Uganda shows a very significant and negative trend for over ten years (Figure 2). This descriptive analysis indicates that there is a relationship between the major forest uses and direct functions, such as wood fuel and wood timber (Figures 4–6 and Table A7). This is necessary because, as the production increased over the years, the forest land cover decreased in East Africa and Uganda in particular.



**Figure 5.** Trend analysis of wood fuel, round wood, and industrial wood production quantities over time (1980 to 2018) in Uganda.



**Figure 6.** Trend analysis of wood fuel, and round wood production quantities over time (1980 to 2018) in Uganda, Kenya, Tanzania, and Rwanda. Source: Authors' Analysis.

As a result, this will significantly lower the quality and diversity of readily available biomass for consumption unless the harvest intensity is controlled. However, due to the high degree of dependency of sub-Saharan Africa on biomass, the hunt for biomass drives deforestation in the region. Hence, biomass utilization in sub-Saharan Africa is an expansive subject that directly and indirectly affects the vast and daily undertakings of the population in this region [45,46].

The studies show that deforestation has greatly reduced the land area once covered by closed-canopy tropical forest in Uganda, with a resulting annual loss rate of 7%. Hence, deforestation rates are high in Uganda, embroiling the country in a continuous state of loss of forest area.

Ugandans heavily use firewood and charcoal biomass as primary cooking fuels, thereby hence high rates of forest area loss. Furthermore, commercially utilized biomass, such as timber for construction, also has a detrimental impact on Ugandan forest development [1,47,48]. Josephat [47] found that over-harvesting of fuelwood biomass resulted in a deforestation-induced scarcity of fuelwood biomass in proximate forests. Therefore, wood biomass consumption in Uganda increased deforestation during the period 2007–2012, forcing locals to source low-quality fuelwood biomass from surrounding areas. However, bioenergy production from wood and other kinds of vegetation biomass and their residues is being used as a sustainable alternative source of energy with an extraordinary level of acceptance in various contexts including the general public, government policies, and many European countries [49–52]. This suggests that developing countries like Uganda and Kenya should embrace it. It has the potential to reduce the amount of wood fuel produced as consumption and demand will

reduce. This would mean that the trend in wood fuel would fall rather than increase as it has for over five decades and continues to do with sharp increases since 2000 [53,54].

Fuelwood biomass and or charcoal are the main sources of energy for the people in Uganda. This is the case for most rural sub-Saharan African communities as well as cities, whose demand for energy is met by biomass in the form of wood and charcoal for household cooking meals and boiling drinking water [55]. Illegal and unsustainable fuelwood biomass harvesting has been observed to compromise forest structure and species richness. Continued harvesting by forest-dependent communities was observed to further contribute to system degradation and a deceleration in forest regeneration. Therefore, biomass harvesting is a factor that drives deforestation in Uganda and limits forest development in many regions [1,2,8].

Many communities in the East African region are dependent on firewood (for rural areas) and charcoal (for urban areas).

The trend shown in Figures 4–6 confirms the correlation between the two, i.e., charcoal production and deforestation. For example, the deforestation situation seems to become worse rather than improve.

Considering the argument of this study that most African and Ugandan households still use traditional cooking stoves [1,2], we propose the use of the locally Improved Eco-Stoves (IES) illustrated in Figure 7C,D. These IESs can easily be made from materials (clay, soil mud, and bricks, among others) found in most parts of the world. The justification for use of IESs is in the consideration of the traditional cooking stoves which do not only waste wood but also pollute the environment as well as posing a health hazard for the household [30–35]. In this case, IESs save both the environment and the people who use them.



**Figure 7.** Cooking stoves (A,B). Locally Improved Eco-Stoves (C,D). Source: Authors' photos.

#### 4.3. The Advantages of IESs

- The stove's materials and design help to retain heat longer; as a result, the plates stay hot for up to five hours, making it easier for people to cook food without constant supervision.



- The environment also benefits from such stoves since they produce significantly fewer greenhouse gases due to more efficient combustion.
- The stove uses less firewood (60% less wood and charcoal), hence reducing the rate of deforestation due to charcoal and firewood production for household and commercial purposes.
- It also helps the rural poor to save by reducing their expenditure on biomass products from firewood and charcoal, which are very expensive.
- These stoves are energy-efficient, and the construction process uses low-cost materials.

Moreover, while in pursuit of a remedy for reducing firewood and charcoal use, we asked about choice of energy alternatives' use and the results are not disquieting since, as illustrated in (Table A6), most of the respondents chose gas (58%), 36% chose electricity, and 7% biogas. This means that if the people are given an opportunity with cheaper alternatives such as gas, electricity, and or biogas (Table A6) they would contribute highly to forest conservation rather than be the cause of it by substituting wood fuels.

## 5. Conclusions

The goal of this study was to comprehensively analyze charcoal and wood fuel utilization processes in Uganda and Sub-Saharan Africa. The environmental and socioeconomic dynamics and implications were critically analyzed.

Based on our findings, there is overexploitation of wood biomass in Uganda, with over 90% of households using charcoal and or firewood. This explains also the very sharp trend in the time series analysis for wood production as well as a decrease in the rate forest land cover mostly due to deforestation. Hence, it is imperative that an alternative source of energy be developed and exploited to reduce the pressures of deforestation arising from wood biomass utilization, and particularly consumption, in Uganda.

On the other hand, charcoal was found to be a source of livelihood for various households especially the women who dominate the charcoal retail and wholesale business as well as water and energy together with the food nexus in Uganda.

Moreover, our research indicates that biomass has severe health implications for children and women given the fact that they are responsible for collecting and transporting fuelwood biomass to their households. Ultimately, the smoke released from burning firewood contains pollutants that are a risk to human health when inhaled. Therefore, it is of the utmost importance to provide alternatives to biomass to help reduce the health complications arising from the use of traditional cooking stoves and firewood hence the need for IESs which are very efficient in combustion.

It is also of the utmost importance to immediately obtain information on the dynamics between biomass production and deforestation in order to further elucidate the state of deforestation in Uganda and provide remedial solutions in the light of preserving biodiversity and meeting increasing needs due to the growing population and urbanization.

We propose the following sustainable policies given the nature of charcoal use dynamics and implications as analyzed herein:

- a subsidy is necessary to train local artisans (blacksmiths, potters) and users who will sustain the creation of local technical capacity to build locally Improved Eco Stoves (IESs);
- campaigns, demonstrations, and promotions to guarantee future remediation to save diminishing forests.
- application of macroeconomic policies that support the importation of cleaner and cheaper alternatives, such as cooking gas, for both urban and rural households that would reduce forest degradation and deforestation; and
- increase the private sector's interest in IESs and other energy alternatives and inform communities about their advantages.

Nonetheless, utilization of wood biomass, if managed well, has the potential to solve renewable energy issues in the future in Uganda and across the globe. We suggest strengthening local governance capacities, supporting private nurserymen in the fuelwood production industry, disseminating simple technology to households while reducing biomass consumption, improving the yield from wood carbonization, to eventually reduce the pressure on forest resources. Future studies could focus on citizens' willingness to pay for Improved Eco-Stoves and alternative sources to reduce deforestation in the region.

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## Appendix A

Analysis from the primary data.

**Table A1.** Household charcoal/firewood use.

Wood Fuel or Charcoal	Frequency.	Percent	Cumulative Percent.
Yes	183	91.96	91.96
No	16	8.04	100.00

**Table A2.** Tabulation of residence by wood fuel/charcoal.

Residence	Wood Fuel or Charcoal		
	Yes	No	Total
Urban	118	11	129
	91.47	8.53	100.00
Rural	65	5	70
	92.86	7.14	100.00
Total	183	16	199
	91.96	8.04	100.00

**Table A3.** Household (HH) monthly wood fuel values/cost (what the household pays for their charcoal/firewood).

HH Wood Fuel Cost	Frequency.	Percent	Cumulative.
UGX 10,000	41	20.60	20.60
UGX 10,000–20,000	28	14.07	34.67
UGX 20,000–30,000	38	19.10	53.77
UGX 30,000–40,000	39	19.60	73.37
UGX 40,000–50,000	21	10.55	83.92
UGX 50,000–100,000	21	10.55	94.47
UGX 100,000+	11	5.53	100.00

**Table A4.** Tabulation of sex by wood fuel/charcoal.

Sex	Wood Fuel or/Charcoal		
	Yes	No	Total
Male	112	8	120
	93.33	6.67	100.00
Female	71	8	79
	89.87	10.13	100.00
Total	183	16	199
	91.96	8.04	100.00

**Table A5.** Household income by wood fuel charcoal use.

Income	Wood Fuel or Charcoal		
	Yes	No	Total
<\$500	44	7	51
	86.27	13.73	100.00
\$500–1000	38	0	38
	100.00	0.00	100.00
\$2000–4000	27	3	30
	90.00	10.00	100.00
\$1000–2000	29	0	29
	100.00	0.00	100.00
\$4000–5000	23	4	27
	85.19	14.81	100.00
\$5000–10,000	15	0	15
	100.00	0.00	100.00
\$20,000+	5	1	6
	83.33	16.67	100.00
\$10,000–15,000	2	1	3
	66.67	33.33	100.00
Total	183	16	199
	91.96	8.04	100.00

**Table A6.** Preference for alternative source energy.

Energy	Frequency.	Percent	Cumulative Percent.
Gas	115	57.79	57.79
Electricity	70	35.18	92.96
Biogas	14	7.04	100.00

## Appendix B

The tables herein show the variations across some of the data estimates that were used. This data was obtained and organized by the authors.

**Table A7.** Wood fuel estimates in the East African region.

Year	Wood Fuel Uganda	Roundwood Uganda	Wood Fuel Kenya	Roundwood Kenya	Wood Fuel Tanzania	Roundwood Tanzania	Wood Fuel Rwanda	Roundwood Rwanda
1980	25,774,334	27,173,334	12,931,470	14,328,470	16,461,416	17,634,016	4,520,000	4,796,000
1981	26,183,326	27,613,326	13,320,678	14,591,678	16,816,743	17,965,843	4,687,000	4,973,000
1982	26,311,766	27,775,766	13,758,209	15,054,209	17,162,740	18,343,940	4,860,000	5,157,000
1983	26,467,010	27,963,010	14,205,376	15,580,376	17,518,530	18,740,530	5,052,000	5,266,000
1984	27,016,058	28,544,058	14,651,233	16,151,233	17,684,399	18,976,399	5,402,000	5,634,000
1985	27,670,284	29,230,284	15,035,821	16,576,821	17,982,916	19,320,916	5,602,000	5,842,000
1986	28,171,586	29,764,586	15,359,507	16,940,507	18,119,682	19,674,682	5,602,000	5,842,000
1987	28,472,836	30,098,836	15,709,988	17,332,988	18,280,393	20,124,393	5,602,000	5,842,000

Table A7. Cont.

Year	Wood Fuel Uganda	Roundwood Uganda	Wood Fuel Kenya	Roundwood Kenya	Wood Fuel Tanzania	Roundwood Tanzania	Wood Fuel Rwanda	Roundwood Rwanda
1988	28,573,012	30,225,012	16,050,412	17,722,412	18,359,400	20,227,400	5,602,000	5,842,000
1989	28,856,856	30,549,856	16,420,361	18,134,361	18,424,256	20,329,256	6,368,000	6,608,000
1990	29,265,482	31,004,482	16,792,606	18,535,606	18,567,195	20,513,195	6,368,000	6,388,000
1991	29,865,918	31,678,918	17,247,700	19,022,700	18,921,098	20,909,098	6,368,000	6,388,000
1992	30,679,212	32,671,212	17,753,655	19,557,655	19,432,612	21,701,612	6,368,000	6,428,000
1993	31,225,080	33,418,080	18,217,617	20,050,617	19,841,753	22,009,753	6,368,000	6,428,000
1994	31,932,026	34,378,026	18,555,475	20,416,475	20,163,261	22,294,261	6,368,000	6,479,000
1995	32,181,392	34,880,392	18,866,384	20,753,384	20,435,063	22,608,063	5,148,000	5,377,000
1996	32,622,348	35,430,348	19,120,528	21,032,528	20,591,740	22,802,740	5,550,000	5,798,000
1997	33,045,024	35,967,024	19,399,053	21,334,053	20,697,360	22,943,360	7,100,000	7,415,000
1998	33,368,100	36,409,100	19,386,779	21,342,779	20,678,131	22,958,131	7,200,000	7,526,000
1999	33,726,320	36,901,320	19,520,854	21,497,854	20,737,167	23,051,167	7,500,000	7,836,000
2000	34,090,320	37,265,320	19,658,247	21,635,247	20,786,647	23,100,647	5,000,000	5,400,000
2001	34,611,016	37,786,016	19,826,903	21,697,903	20,950,514	23,264,514	5,000,000	5,495,000
2002	35,141,824	38,316,824	20,001,528	21,843,528	21,124,758	23,438,758	5,000,000	5,495,000
2003	35,682,952	38,857,952	20,182,351	21,942,351	21,309,584	23,623,584	5,000,000	5,495,000
2004	36,234,600	39,480,600	20,369,621	22,161,621	21,505,209	23,819,209	5,000,000	5,495,000
2005	36,797,000	40,120,000	25,600,000	26,714,000	21,711,852	24,025,852	5,000,000	5,495,000
2006	37,343,297	40,746,297	26,400,000	27,646,000	21,913,959	24,227,959	5,000,000	5,495,000
2007	37,900,200	41,685,200	26,400,000	27,646,000	22,127,200	24,441,200	5,000,000	5,495,000
2008	38,467,800	42,357,800	26,400,000	27,636,000	22,351,700	24,665,700	5,000,000	6,211,000
2009	39,046,470	43,029,470	26,400,000	27,479,000	22,587,785	24,901,785	5,000,000	6,211,927
2010	39,636,358	43,729,358	26,400,000	27,533,000	22,835,697	25,149,697	5,000,000	6,211,927
2011	41,600,000	45,811,000	26,400,000	27,541,000	23,068,998	25,382,998	5,000,000	6,211,927
2012	41,600,000	45,975,000	26,400,000	27,432,000	23,313,759	25,904,759	5,000,000	6,211,927
2013	41,600,000	46,207,000	26,400,000	27,432,000	23,570,218	26,408,297	5,000,000	6,211,927
2014	41,856,575	46,704,575	26,400,000	27,432,000	23,838,617	26,676,696	5,000,000	6,211,927
2015	42,438,054	47,544,054	26,400,000	27,432,000	24,119,214	26,957,293	5,000,000	6,211,927
2016	42,861,593	48,191,593	26,400,000	27,432,000	24,340,069	27,178,148	5,000,000	6,211,927
2017	43,292,521	48,622,521	26,400,000	27,432,000	24,572,401	27,410,480	5,000,000	6,211,927
2018	43,730,965	49,060,965	26,400,000	27,432,000	24,816,399	27,654,478	5,000,000	6,211,927

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