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Review

Sustainable biomass energy production and utilization in sub-Saharan Africa: A case study of Kenya

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This paper reviews biomass energy production and utilization trends, opportunities, challenges and strategies for sustainability in biomass energy sector in sub-Saharan Africa (SSA). This is because despite various benefits provided by the resource, it receives little attention in terms of policy formulation and planning to enhance adequate investments and allocation of funds. Therefore, with increasing demand rate of 3.3% over 27% of woodfuel in SSA will continue being produced unsustainably using inefficient technologies; leading to a deforestation and degradation rate of over 3.5 million ha per year. The situation is worse in some countries like Kenya where over 40% of biomass energy especially is obtained from arid and semi-arid lands (ASALs) characterized by less than 4% productivity rate due to poor regeneration and vegetation growth rates. Thus there is need to implement various strategies including adoption of improved and efficient production and utilization technologies, increase on-farm tree planting and enhanced tree out-grower systems, enactment and proper implementation of biomass energy policies, establishment of reliable biomass energy database, and recognition of biomass energy benefits to the society. These will foster integration of biomass energy into planning programmes to enhance investments in the sector and reduce biomass energy resource overexploitation.

Key words: Biomass energy, sustainability, policy, technologies, deforestation, degradation.

INTRODUCTION

Africa has three distinct regions with varying energy sources; North Africa which is dependent on oil and gas, South Africa depending mainly on coal while the rest is largely reliant on bioenergy (Figure 1) (Hafner et al., 2018). Out of 28,177 petajoules (pj) of biomass energy produced and supplied in Africa, over 15,575 pj are produced and utilized in the sub-Saharan Africa (SSA) excluding South Africa (Nyika et al., 2020).

This indicates that biomass energy plays a vital role in meeting local energy demand in many SSA countries with over 81% of the population accounting for 653 million people in these countries depending on the resource. SSA depends especially on wood biomass for cooking, heating household and economic activities; a rate that is higher than other regions in the world (Bildiricia and Özaksoy, 2016; Nyika et al., 2020). By 2030, the population relying on biomass energy in SSA is expected to increase to 922 million, increasing its

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Figure 1. Primary energy supply by regions and sources in Africa by 2015.
Source: Hafner et al. (2018).

demand by between 1.4 and 2.8 times (IEA, 2011; UNEP, 2019).

This high dependency can be justified by wide availability of biomass from woodlands, forests, agricultural and industrial wastes (Nyika et al., 2020). However, heavy reliance on biomass energy in SSA is unlikely to change in the near future because of increasing population, unavailability of affordable modern energy such as LPG, kerosene and electricity, and increasing trends towards bioeconomies to combat climate change as stipulated in Paris Agreement goals (Janssen et al., 2012; Reid et al., 2020). Besides being the standard cooking fuel for the majority of sub-Saharan households, biomass is also an important energy resource for small- and medium-scale rural industries and institutions such as tobacco curing, tea drying, brick making, fish smoking, bakeries, restaurants, hospitals, prisons and learning institutions among others.

Despite biomass being the main energy source for over 81% of SSA's population and its renowned role towards climate change mitigation, its sources, production, development and efficient use has not been receiving same attention for a long time compared to commercial forms of energy like oil, gas, coal and electricity (Beuchelt and Nassl, 2019; Republic of Kenya, 2020). Due to this low prioritization of biomass energy, the sector is poorly funded, lacks good governance and does not secure long-term political commitment for formulating and implementing effective policies and strategies that are crucial in ensuring its sustainable production and use. Bioenergy sector also suffers from inadequate and inaccurate data, making it difficult to undertake relevant biomass energy planning and policy formulation (Githiomi and Oduor, 2012). Therefore, there have been low investments to support enabling infrastructures and institutions to integrate emerging efficient technologies like combined heat and power (CHP) into current production and utilization scenarios to ensure sustainable production and utilization of biomass.

This has contributed to inadequate integration of wood energy into national level planning exercises which are important in formulating national priorities that are used in allocation of government investment and resources and prioritization of development objectives and targets (Githiomi, 2010).

The scarcity and uncertainty of wood energy data can be attributed to biomass energy mainly being handled in the informal sector and does not pass through monetized economy like in the case of liquefied petroleum gas (LPG), kerosene and electricity which are alternatives to wood energy.

Due to poor governance, biomass energy especially woodfuel is under-priced due to competition from woodfuel produced through illegal harvesting of wood. Therefore, this paper reviews biomass energy production and utilization trends, opportunities, challenges and strategies for sustainable development in SSA.

BIOMASS ENERGY SUPPLY AND DEMAND IN AFRICA

Out of 4 billion m^3 of wood harvested from forests in 2018, 51 and 49% were used for industrial and woodfuel purposes, respectively (Forest Research, 2020).

Over 93.5% of the wood consumed in Africa is sourced

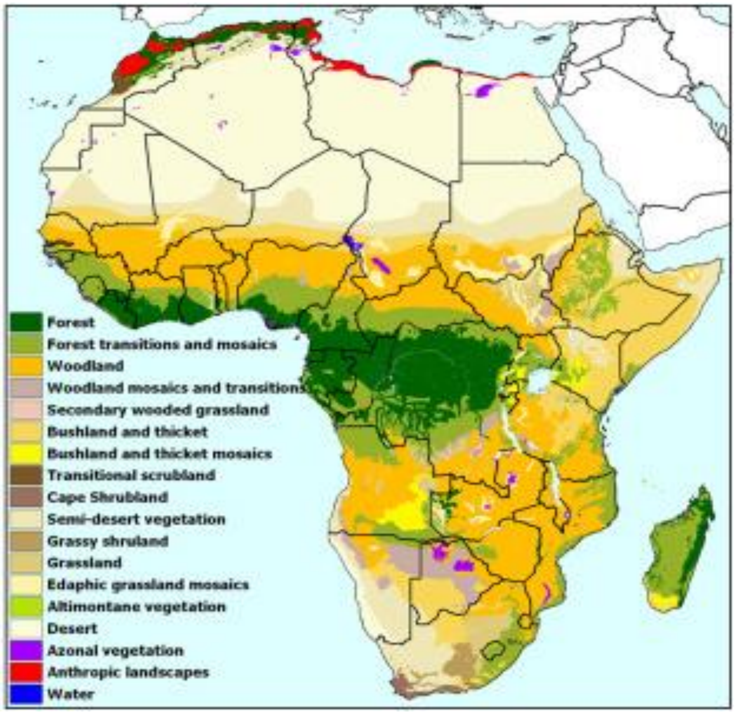

Figure 2. Vegetation distribution in Africa.
Source: Bouveta et al. (2018).

from natural forests especially moist tropical forest regions of the Congo Basin, spanning the Democratic Republic of Congo, Brazzaville Congo, the Central African Republic, Cameroon, Gabon, and Equatorial Guinea (Figure 2). Data on wood production from plantation forests is not clear.

This is because while Global Environment Facility (GEF, 2013) estimated total annual production from Africa's plantations as 46 million m^3, Jürgensen et al. (2014) estimated annual production as 26 million m^3. However, GEF (2013) and Jürgensen et al. (2014) concur that South Africa alone accounts for over 40% of wood produced in Africa's plantation forests.

The total consumption of wood in Africa is about 700 million cubic meters (m^3) per year with approximately 75 million m^3 consumed for industrial wood products and the remaining 625 million m^3 representing over 80% of harvested wood is consumed for woodfuel, with about 29% of this converted to charcoal (GEF, 2013; World Bank, 2016; Harvey and Guariguata, 2020). However, 20% of woodfuel is produced sustainably through agroforestry systems through selection of branches or collection of deadwood (Dagar et al., 2020). As a result, it is estimated that 27 to 40% of woodfuel in SSA including Kenya is produced and used unsustainably with no replanting and dominated by inefficient technologies with less than 10% efficiency (Njenga et al., 2019; IEA, 2019a). Therefore, together with the projected demand increase of wood and woodfuel of over 2.6% (Figure 3), it is unlikely that the Africa's current rate of deforestation and degradation of about 3.5 million ha per year will reduce significantly in the next two decades (GEF, 2013; IEA, 2019b).

In Africa, charcoal usage has been growing at an annual rate of 3.3 for the past 5 decades, and is expected to increase due to urbanization and human population increase (Figure 4) (GEF, 2013). On the other hand, GEF (2013) projects that the overall rate of consumption of fuelwood in Africa will grow at a Compound annual growth rate (CAGR) of 1.7% which is consistent with the overall historical growth rate of 1.8%. However, the rate of woodfuel consumption may reduce by between 34 and 60% by 2040 (excluding South Africa) if there is a shift towards 35 to 40% efficient charcoal conversion kilns and 30 to 40% efficient cook stoves (IEA, 2019b).

According to GEF (2013), millions of families in other parts of the developing world beside Africa also rely on biomass as their primary energy source. However, while the number of people in other developing countries relying on biomass like China, India and Latin America is falling, the number in Africa is increasing (Table 1). The International Energy Agency (IEA, 2011) projects that by 2030, 922 million people in Africa will rely on biomass energy, up from 745 million in 2015. Therefore, though the overall consumption of biomass energy is expected to rise due to the population growth, the share of households in Sub-Saharan Africa relying on biomass energy is expected to decline from 80 to 70% by 2030 as shown in summarized projections (Table 1).

This may be as a result of various efforts by

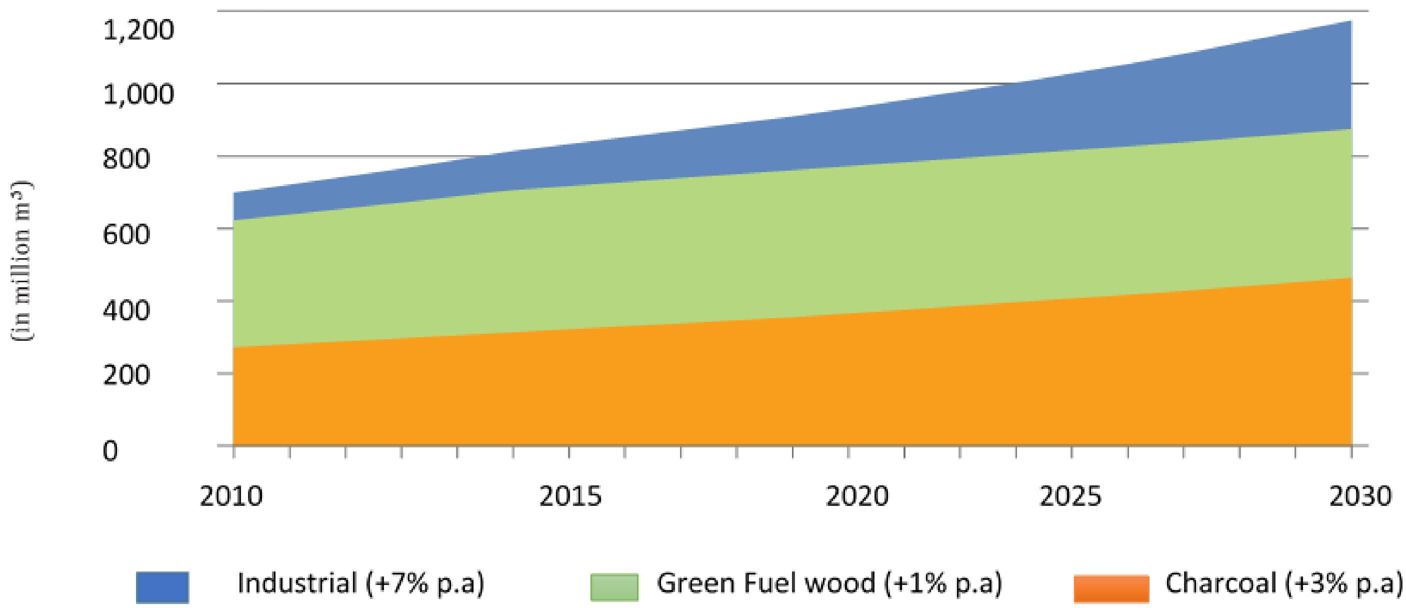

Figure 3. Projected demand of wood and woodfuel in African.
Source: GEF (2013).

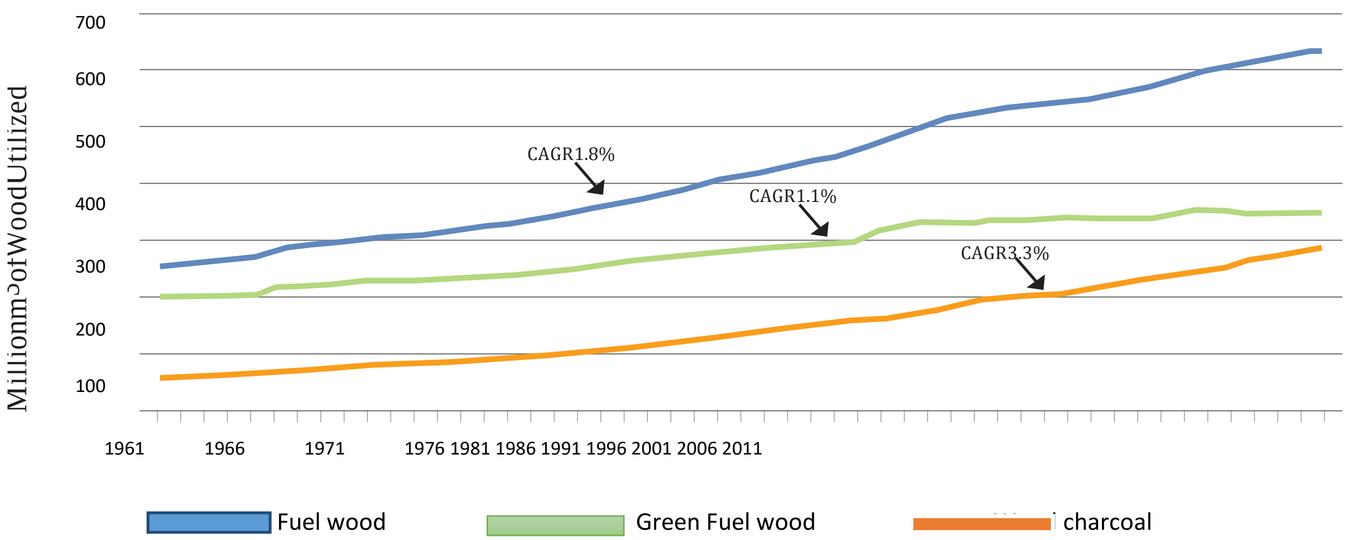

Figure 4. Historical fuel wood usage in sub-Saharan Africa Since 1961 (Charcoal converted at 10 m^3 per ton).
Source: GEF (2013).

governments to increase accessibility to clean and modern energies like electricity in cities and villages.

Daily per capita consumption of woodfuel in Africa differs significantly between countries and within countries (Figure 5). The variations may be as a result of differences in climates with some areas colder than others, differences in household sizes that determine energy demand, education level of household head that influences adoption of efficient technologies, ease of access and availability of biomass resources and affordability of alternative fuels (IEA, 2014; Ndegwa et al., 2020).

A case study of supply demand balance of biomass energy in Kenya

Past wood energy studies in Kenya have shown that the country is not able to match demand and supply leading

Table 1. Biomass as source of cooking fuel globally.

2009 (Actual)				2015	2030	Share of population on biomass		
Region	**Rural**	**Urban**	**Totals**	**Total**	**Total**	**2009**	**2015**	**2030**
Africa	481	176	657	745	922	67	65	61
Sub-Saharan Africa	477	176	653	741	918	80	77	70
Developing Asia	1,694	243	1,937	1,944	1,769	55	51	42
China	377	47	423	393	280	32	28	19
India	765	90	855	863	780	75	69	54
Other Asia	553	106	659	688	709	63	60	52
Latin America	60	24	85	85	79	18	17	14
Developing Countries*	2,235	444	2,679	2,774	2,770	54	51	44
World**	2,235	444	2,679	2,774	2,770	40	38	34
Africa in % of World	22	40	25	27	33	40		

*Includes Middle East countries. **Includes OECD and transition economies.
Source: IEA (2010)

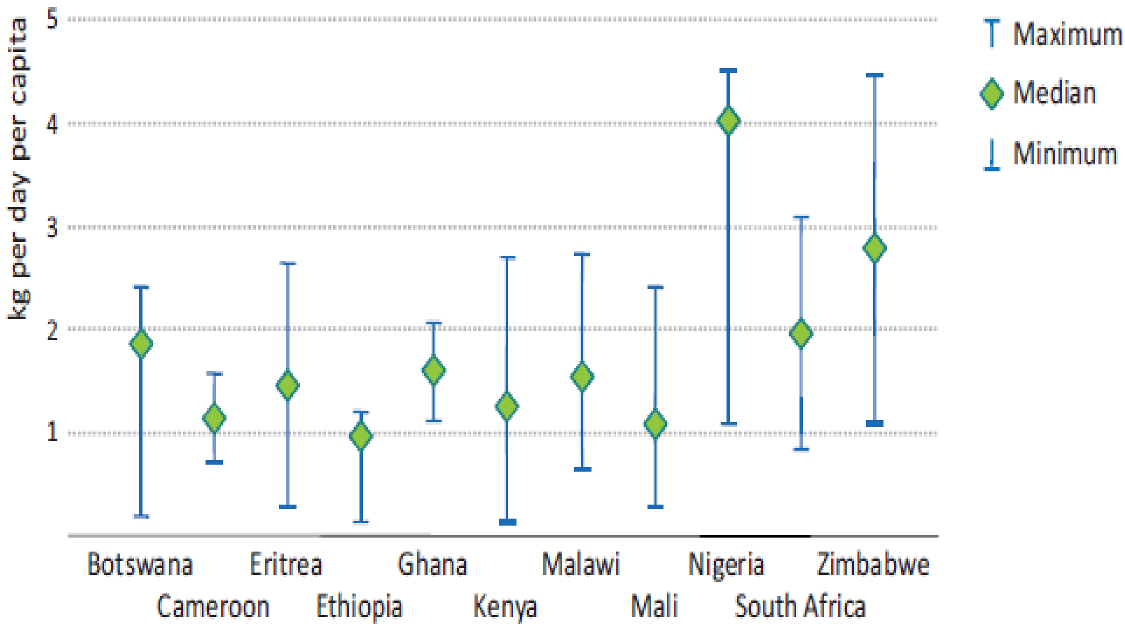

Figure 5. Per daily per capita consumption of woodfuel in Africa by 2019.
Source: IEA (2014).

to deficit in wood energy (Barnes, 1984; KFMP, 1994; Ministry of Energy [MoE], 2002). Biomass supply comes from various forest formations in Kenya, which include: forests, bushlands, grasslands, farm lands, industrial residues and plantations among others, but not all are fully accessible for biomass energy (Table 2). Inaccessibility may be as a result of legal issues especially in closed forest, management objectives, ownership that determines user rights, distance and infrastructures that makes accessibility difficult. However, about 40 to 75% of charcoal consumed in Kenya is produced in the semi-arid and arid lands (ASALs), mainly from woodlands, bushlands and wooded grasslands (Kamwilu et al., 2021). Therefore, woodfuel supply is at risk because ASALs are characterized as having low productivity of 2 to 4% per year and poor regeneration of harvested areas (Miyuki et al., 2014).

The Ministry of Energy MOE (2002) Kamfor report outlines the major changes in biomass consumption, supply and deficit/balances for the years 2000 to 2020 as far as households and cottage industries are concerned. The total annual woodfuel consumption in 2000 was over 34.3 million tonnes compared to sustainable supply of 1 million tonnes translating to over 56% deficit, which has

Table 2. Sources of biomass energy in Kenya.

Source	Approx. Size (ha)	Annual productivity(M^3/ha/year	Approximate annual yield (million m3)	Accessibility (%)
Closed Forests	1247,400	1.3	1.62	5
Woodlands	2,092,600	0.64	1.34	30
Bushlands	24,629,400	0.44	10.84	30
Wooded grasslands	10,600,000	0.25	2.65	30
Grasslands	1,203,500	0.08	0.10	10
Farmlands	10000,000	1.44	14.40	90
Forest Plantations	91,000	19.9	1.81	35

Source: Takase et al. (2021).

actually reached 60% by 2021 (Takase et al., 2021). This increase may be attributed to higher woodfuel annual demand that has been growing at 2.7% per year compared to sustainable supply production that has been decreasing by 0.6% per year (Mugo and Gathui, 2010; Simiyu, 2010).

This is as a result of increasing inaccessibility to affordable alternative sources of energy, increasing human population and expanding economies that largely rely on firewood and charcoal. Continued supply of woodfuel on unsustainable basis leads to imbalance in timber supply, increased forest degradation that may lead to lose of ecosystem services provided by forests, switching to low grade biomass fuels like agricultural residues that have high emissions, and reduced food supply due to increased land use competition for agriculture and forestry.

BIOMASS ENERGY OPPORTUNITIES IN KENYA

Compared to fossil fuel-based energy sources like kerosene and LPG that are imported and affect countries' macro-economic balance sheets, sustainable biomass energy has the ability to support rural communities' livelihood improvement and poverty alleviation. In Kenya, biomass energy sector especially woodfuel contributes over Ksh 32 billion to the Kenyan economy annually, employs over 1 million people (producers, transporters and vendors) and supports the livelihood of over 2.5 million people along the value chain (Njenga et al., 2013; UNEP, 2019).

Over time, monthly income from woodfuel production especially charcoal has been increasing in Kenya (Figure 6). According to Ndegwa *et al*. (2020, 2021), income from charcoal sales contributes over 50% of household's monthly income for many charcoal producing households; thus charcoaling is an important source of livelihood. Though the gradual increase in charcoal prices over the years may be insignificant when adjusted for inflation (Bailis et al., 2017), the money helps them meet basic needs like building good houses for shelter, buy food, paying school fees for their children and buying cloths.

However, charcoal producers enjoy less than 24% of total profits on the charcoal value chain while vendors and transporters enjoy over 63% of profits on the value chain (Republic of Kenya, 2013). Therefore, the potential of biomass energy for economic, social and cultural development is enormous. During COVID-19 pandemic, when people were losing jobs, charcoal production provided job opportunities. This is because it is an economic activity that requires low capital and operational cost.

Therefore, there is need to modernize wood based biomass markets for both fuelwood and charcoal as an opportunity for stakeholders to engage formally in the sector. Modernizing the wood-based biomass energy sector has the potential of significantly increasing the revenue base of most communities in Kenya especially those in ASALs and the government at large. For example, in Kenyan government losses over 21.6 billion annually due to illegal charcoal production and lack of value added tax on charcoal, with licenses and business permits being the only source of revenue for the government (Republic of Kenya, 2013).

There also exist opportunities for Kenya to use sustainable biomass energy to mitigate climate change especially when produced from short rotation plantations. Biomass, when used as fuel, does release carbon dioxide (which is one of the major greenhouse gases) just like fossil fuels. However, when new trees are planted to replace those which are used as fuel (and properly managed without over exploitation), the new growth takes up more or less the same amount of carbon dioxide with the result that biomass energy, when used in a sustainable manner, is in principle carbon dioxide neutral, unlike fossil based fuels (Auke, 1995; Gustavsson, 1999; Stuart, 2000). The practice of using woodfuel saves enormous amount of carbon dioxide which would otherwise be released into the atmosphere from alternative fossil fuel use.

Besides wood fuel, there is potential for other biomass energy sources which include briquettes, pellets and

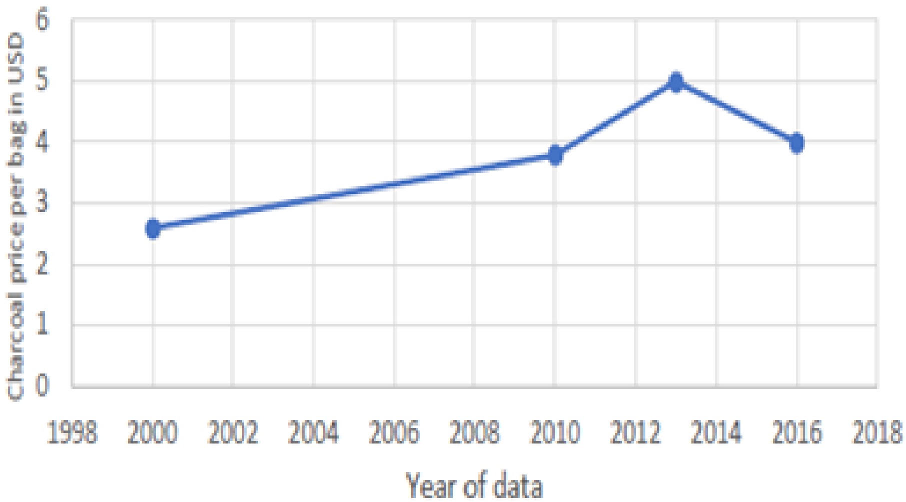

Figure 6. Charcoal prices in Kenya per bag.
Source: Ndegwa et al. (2020).

wood chips. Their production and use in Africa is still very limited. Briquetting and pelleting compresses, densifies and enhances homogeneity of loose combustible materials to reduce challenges encountered while using agricultural and forest residues including low energy density (Akande and Olorunnisola, 2018).

There has been an attempt to produce heat and electricity from wood chips in Kenya. Companies like Cummins power generation in Kenya attempted to produce electricity from the invasive Prosopis species.

Although technologies for production of bio-diesel from biomass feed stocks have been known for a long time, there are very few experiences of wide scale commercial production and use in Africa. Biodiesel production in the region has mainly been on pilot initiatives.

CONSTRAINTS TO SUSTAINABLE BIOMASS ENERGY PRODUCTION AND UTILIZATION

Some of the constraints to sustainable biomass production and use involve both policy and technical issues which include the following/

Lack of adequate policies and strategies to address the challenge

The fundamental challenge has been lack of effective policies and strategies to address the growing challenges in its production and use. Countries like Kenya that has enacted policies and Acts like Energy Act 2019 encounter various challenges including lack of cooperation among stakeholders like charcoal producer association groups and lack of sustained political good will. The Government of Kenya (GoK) for example introduced a ban on charcoal production in 2018, which is a poor policy strategy in ensuring sustainability because it increases illegal harvesting of trees and production of charcoal activities, demoralizes the community to engage in sustainable forest and tree management, expansion of invasive species that were initially managed through utilization, encourage over exploitation in private firms and increases corruption as producers bribe police and other law enforcers.

As a result of poor policies in SSA, there have been little investments in the biomass energy sector as most investments are taken by the commercial energy sources (petroleum based fuels and electricity) as shown in Figure 7.

Inadequate emphasis on biomass energy accessibility

Globally, policy debates on energy supply have mostly ignored woodfuels, but instead emphasized the need for the poor to gain access to ‘modern’ energy sources such as kerosene, liquefied petroleum gas (LPG) and electricity (Owen et al., 2013). However, the reality is that modern energy sources are unlikely to provide primary household energy needs for most of the poor communities in SSA for some years to come. This is because increasing rural poor communities who cannot afford modern energy sources leads to increased use of biomass energy (Figure 8).

Scarcity and uncertainty of biomass production and consumption data

Data on biomass energy supply and demand in most Africa countries are scarce and characterized by a high

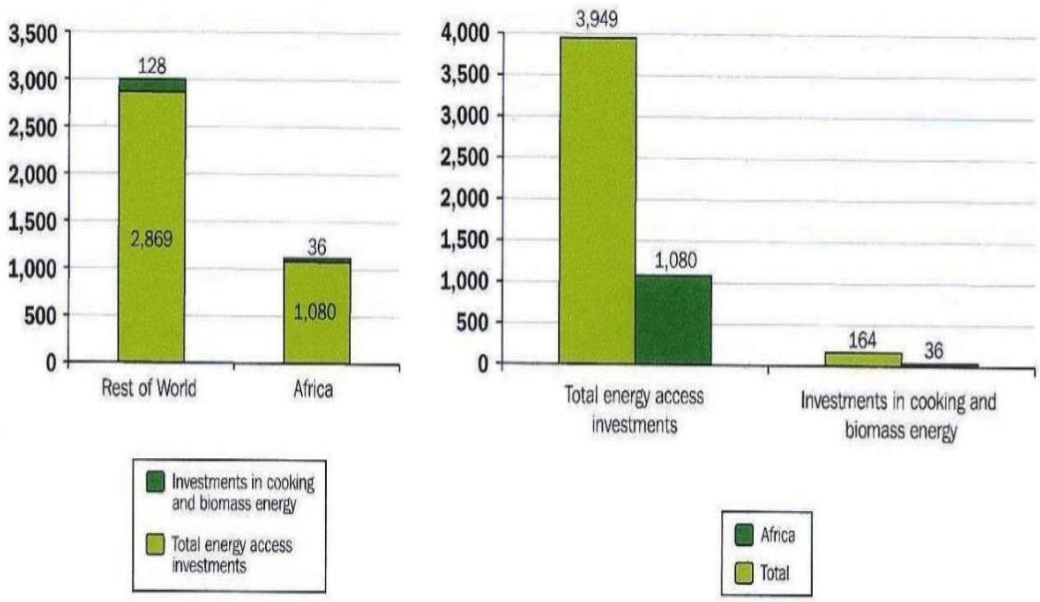

Figure 7. Investments in biomass energy and other commercial sources of energy.
Source: World Bank (2016, 2011).

Figure 8. Link between biomass use and poverty.
Source: Karekezi et al. (2004).

degree of uncertainty that makes it difficult to undertake relevant wood energy planning and policy formulation (Miyuki et al., 2014). This has led to lack of integration of wood energy into national level planning exercises, which is important in formulating national policies that are used in allocation of government investment and resources

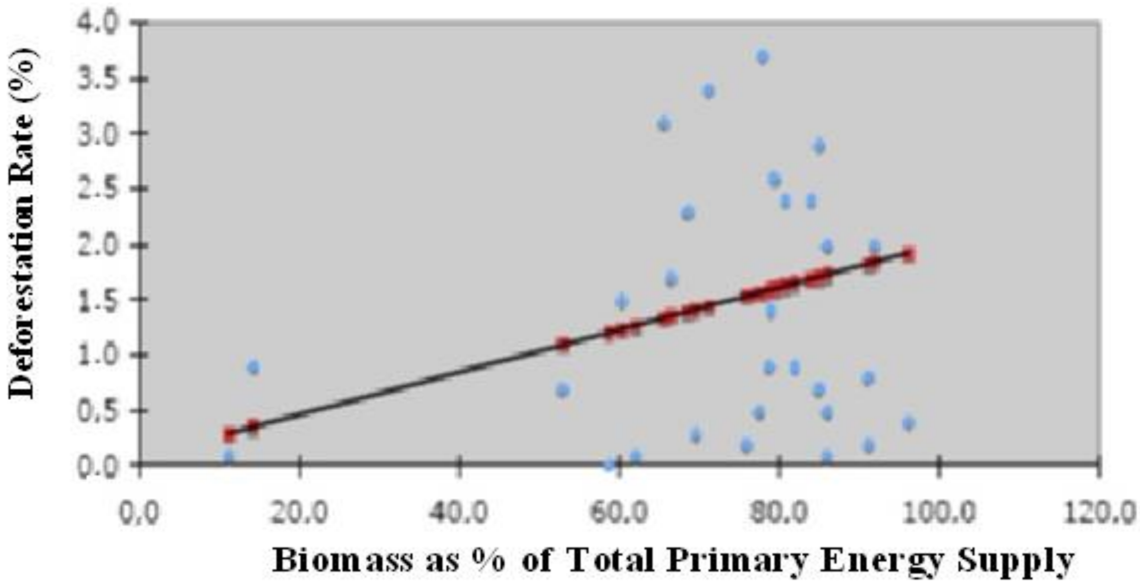

Figure 9. Deforestation and biomass energy use.
Source: IEA and World Bank.

and prioritization of development objectives and targets (Githiomi, 2010). The scarcity and uncertainty of wood energy data is because biomass energy is mainly handled in the informal sector and does not pass through monetized economy like in the case of LPG, kerosene and electricity which are alternatives to wood energy.

Inefficient production and utilization technologies

Generally, traditional kilns and cook stoves are used which results in low conservation efficiency and increased health hazards. A wide range of interactions in many SSA countries have tried to overcome these challenges by promoting more efficient kilns for charcoal production but adoption rate has been limited (AFREA, 2011). The low adoption rate is due to informal and often illegal nature of charcoal production where higher material cost, illegal harvesting of trees, increased labour input and lack of skills act as disincentives to charcoal producers to adopt improved technology. In terms of utilization technologies, Karanja and Gasparatos (2020) established that only 38.5% of households in Murang'a County have adopted improved biomass stoves as their primary stoves despite marketing and distribution of clean cooking solutions efforts through developmental programmes.

Inadequate incentives for biomass energy sustainability

The woodfuel value chain is also characterised by the presence of many actors, informal practices and often unequal distribution of benefits, leading to a situation where there is little incentive to extract woodfuel sustainably with the poorest groups marginalised the most. Woodfuel prices in many African countries do not reflect the replacement costs as fuelwood/charcoal producer are not obliged to replace or pay for the trees that they extracted. This has led to unsustainable harvesting of the resource.

Overreliance on trees from ASALs

Establishment of trees in ASALs is limited due to damage of young regenerated samplings by animals. Charcoal in most of African countries like Kenya is produced in ASALs where there is also high population of domestic animals, leading to low regeneration and growth rates of vegetation.

Perceived negative impacts of woodfuel utilization

Deforestation and forest degradation is a major problem created by the current energy consumption patterns in Africa. The negative environmental impact of cooking with wood-fuels is increasing in most African countries. Poor forest management and increasing demands are leading to increased level of land deforestation (Figure 9).

This translates to increased inaccessibility of the resource as evidenced by rural women increasingly their daily trips to gather fuel-wood as well as increased gathering time and increased household's budgetary allocations on woodfuel (Namaswa et al., 2016). It may also lead to reduced profits for woodfuel producers and vendors due to increased cost of transportation from production sites.

POSSIBLE STRATEGIES FOR SUSTAINABLE BIOMASS ENERGY PRODUCTION

The scenarios parameters used in biomass energy planning include projection of sustainable supply and demand from the base year when baseline survey is conducted up to the end of planning period. Through matching sustainable supply and expected demand within the planning period, various scenarios are developed with their implementation strategies aimed at bridging the gap between sustainable supply and demand.

The scenarios are either based on supply side or demand side strategies. The following supply and demand interventions can be adopted to ensure sustainable biomass energy production and utilization.

Adoption of improved and efficient production and utilisation technologies

There is need for research and development of improved and efficient biomass energy production and utilization technologies.

This can be achieved through strengthening research and development institutions, encouraging multi-disciplinary and multi-institutional research through bio-energy innovation platforms to ensure that the developed technologies are efficient, affordable, simple, easy to use and consider user needs including cooking comfort, health issues and safety (Githiomi and Oduor, 2012; Republic of Kenya, 2020). This is important to ensure enhanced adoption of these technologies at all levels of production and utilization. More efficient production technologies like charcoal kilns would lead to a reduction of wood needed for charcoal making significantly while improved stoves will also reduce demand for firewood and charcoal as well as air pollution (Bailis et al., 2005; WHO, 2006). Improved technologies should also be developed to use alternative biomass energy resources including briquettes from forests and agricultural residues, pellets from wood chips, bioethanol, biogas and biodiesels to reduce pressure on forest resources.

Enhanced on-farm tree planting and out-grower schemes

Improving biomass energy production systems through promotion of on-farm tree planting with out-grower tree schemes can enhance sustainable biomass production in Africa. Agricultural sector has a key role to play in supplementing biomass energy demand through integrating trees in farmlands for energy production. Kenya has been successful in on-farm tree farming in areas that do not have problems with land ownership. This has helped to ease pressure on the natural forest and also satisfy the biomass energy needs of the local communities. Currently, the emphasis in forestry sector in some African states is industrial plantations for timber production. However, this policy direction should change to have some areas allocated for woodfuel plantations using short rotation systems. This can be enhanced through development of improved tree genetics to improve growth rates, biomass productivity, resistance to diseases and unfavourable weather conditions. The success of this strategy will also require identification of tree species that provide positive interaction with crops and provision of technical advice to tree growers (Githiomi and Oduor, 2012).

Enactment and implementation of appropriate biomass energy policies

According to Kenya Bioenergy strategy 2020-2027, biomass energy policies should be geared towards ensuring sustainability, adequacy, competitiveness, secure and reliable supply of biomass energy to meet prevailing demand while protecting and conserving the environment. This is important in ensuring self-reliance in biomass energy production. However, this has been difficult to achieve in most African countries because of uncoordinated policy formulation frameworks on biomass energy initiated by different ministries and state departments. In Kenya for Example, there have been weak coordination and linkages among concerned agencies like forestry, agriculture, energy and industry sectors. Decentralized area based wood energy planning is the most suitable for different ecological areas as wood energy situation and problems are site-specific and vary from one region to the other (FAO-RWEDP, 1995).

Development and maintenance of credible and reliable biomass energy database

Most SSA countries have scanty and unreliable data and statistics on biomass energy resources, consumption patterns, trends and future predictions, a factor that has contributed to weak policies, poor decision-making and inadequate investments. Improvement of biomass energy database in African countries with unified data collection methodology is key aspect which will guide policy formulation and planning. Biomass energy databases should be established at regional, national and county/ local levels through establishment of regular field surveys on supply, demand and data analyses to monitor thechanges over time. Regular surveys need to be undertaken preferably at five year intervals to enable updating the data.

Recognition of economic and environmental benefits of biomass energy

Recognizing biomass energy economic and environment roles in both forest and non-forest areas is important if it has to be allocated resources for its sustainability. Some of the environmental values to be considered include carbon dioxide fixation by trees grown sustainably, improvement of ecosystem, and conservation of biodiversity among others.

CONCLUSIONS

Biomass energy resources that constitute the largest share of primary energy for domestic and small and medium-term businesses, and known to provide employment along its value chain is not well managed, experiences low investment rates and is at risk of being overexploited.

This therefore is calling for an enabling environment for policy-makers, professionals, investors and other stakeholders to integrate biomass energy into national planning programmes by addressing possible gaps to ensure sustainable supply of the resource at a reasonable cost.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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