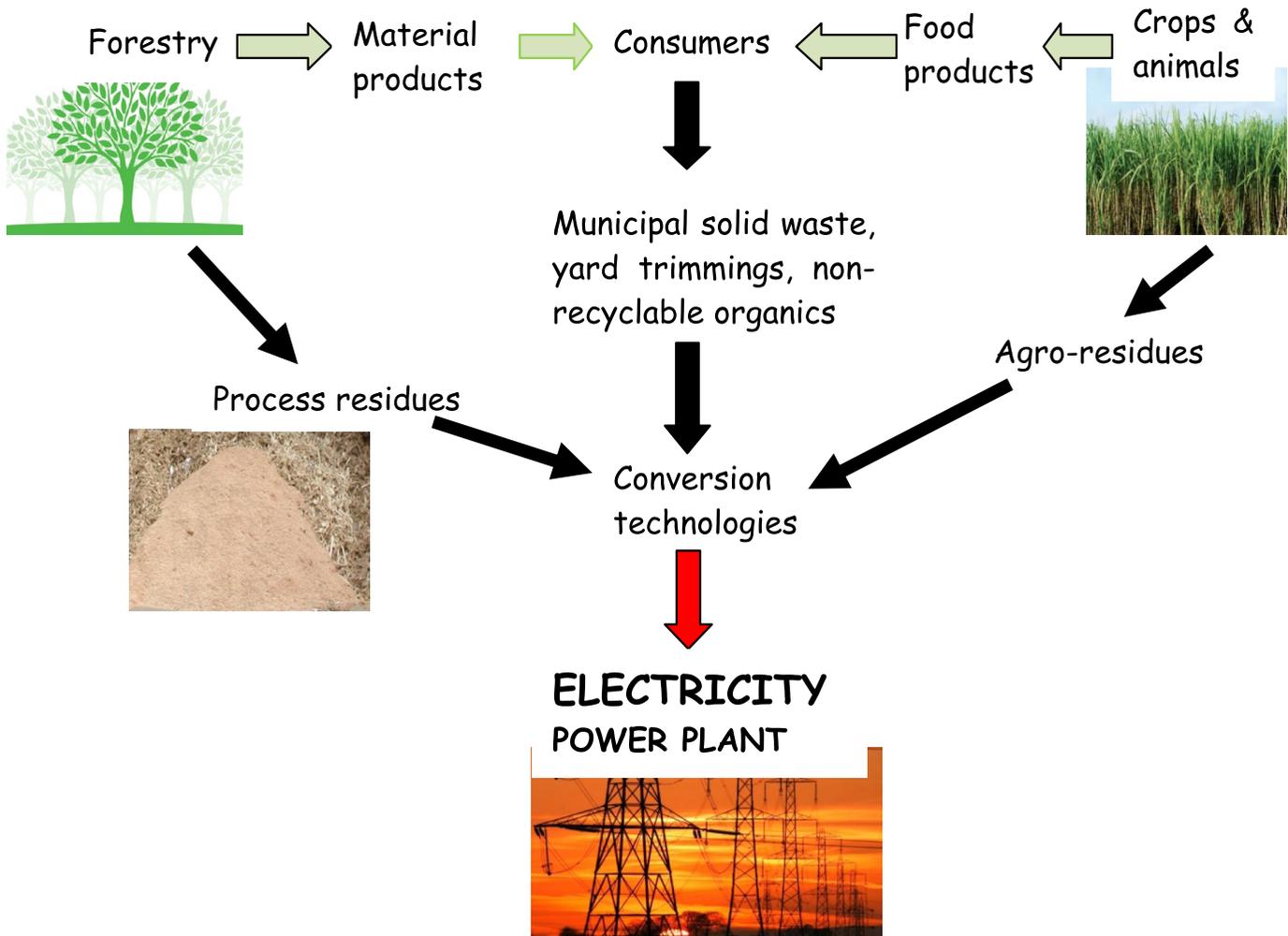


BIOMASS TO ELECTRICITY



PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Temporal and spatial analysis of electricity generation from biomass sources in sub-Saharan Africa

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Cogent Engineering (2017), 4: 1296757



Received: 09 December 2016
Accepted: 14 February 2017
First Published: 21 February 2017

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Reviewing editor:
Wei Meng, Wuhan University of Technology, China

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PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Temporal and spatial analysis of electricity generation from biomass sources in sub-Saharan Africa

Raphael M. Jingura¹ and Reckson Kamusoko^{1*}

Abstract: The paper analyses the generation of electricity from biomass sources in sub-Saharan Africa (SSA) between 2003 and 2012. The electrification rate in SSA was 32% as compared to 92, 70 and 94% in China and East Asia, South Asia and Latin America, respectively. This is a serious issue that affects development. An estimated 620 million people in SSA have no access to electricity. Yet SSA abounds in biomass resources, it produces less than 1% of its electricity from biomass. The structure of electricity production in SSA shows that generation mix is dominated by hydropower (23%) and fossil fuels (73.3%). There has been a significant temporal variation in the quantum of electricity produced from biomass in SSA between 2003 and 2012. The trend has been rather static. Only 13 countries in SSA produce electricity from biomass sources. However, there are significant spatial variations with Eastern and Southern Africa producing more electricity from biomass sources than Western Africa.

Subjects: Renewable Energy; Energy & Fuels; Technology

Keywords: biomass; electricity; hydropower; production; sub-Saharan Africa



Reckson Kamusoko

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PUBLIC INTEREST STATEMENT

The world's main user of biomass energy is Africa. The exploitation of biomass energy for cooking and heating is common in sub-Saharan Africa (SSA). More than 635 million people in SSA have no access to electricity. Biomass has the potential to meet the basic needs, and contribute to sustainable development and rural livelihoods. However, it is often utilised in its unprocessed form with severe negative impacts on the environment and may pose serious hazards to human health. Improvement and modernisation of biomass via sustainable conversion technologies can contribute to supplying future electricity demand. This article describes the trend in electricity generation from biomass in SSA. It focuses on disaggregating electricity production to show the contribution of biomass to the electricity production structure. Some temporal and spatial variations in relation to the use of biomass to produce electricity were observed. There is limited use of biomass (0.3%) in SSA to generate electricity. The electricity supply mix in SSA is dominated by fossil fuels and hydropower.

1. Introduction

It is a known fact that energy is essential for human development. In fact, energy poverty is one of the biggest challenges in developing countries. Among energy forms, electricity is an indispensable ingredient of economic development (Obser'Ever, 2013). Centralised electricity generation and distribution are essential trends of a modern society (Dasappa, 2011). Increase in electricity production translates into better quality of life and the creation of wealth (Obser'Ever, 2013). In some instances, even though a controversial indicator, per capita electricity output can be used as an indicator of the differences in development between countries. For example, North America is a developed region whose per capita electricity output is 14,167 kWh and is almost thirty times that of sub-Saharan Africa (SSA) at 490 kWh cap⁻¹ (Obser'Ever, 2013).

SSA is one of the regions in the world that has high levels of underdevelopment. By definition, SSA is the African region south of the Sahara. As observed by Eleri and Eleri (2009), poverty and the challenge of energy are inextricably linked in Africa. The poverty-energy nexus is problematic in SSA and is related to various other challenges in the region, for example, such as lack of entrepreneurship opportunities. The International Energy Agency [IEA] (2014) highlights the problem of access to electricity in SSA. An estimated more than 635 million people in SSA do not have access to electricity, and for those that do have it, supply is often insufficient, unreliable and among the most costly in the world (Organisation for Economic Co-operation & Development/IEA, 2016). This is ascribed to fast population growth and to the failure of local governments in defining sound electrification policies (D'Amelio, Garrone, & Piscitello, 2016). What is worth noting is that there is an escalation in the population in SSA without access to electricity from about 587 million people in 2009 to above 635 million in 2016.

IEA (2012) data reveal global trends in electrification rates. SSA has the lowest level of electrification in the developing world. The electrification rate in SSA is 32% compared to 92, 70 and 94% in China and East Asia, South Asia and Latin America, respectively. The electrification rates in SSA differ widely among nations, from very low levels in South Sudan (1%), Central African Republic (3%) and Chad (4%) to very high levels in the islands of Seychelles (99%), Reunion (99%) and Mauritius (100%) (IEA, 2016). The use of electricity in many SSA countries is typical of high-income households as well as commercial and industrial activities (Karekezi & Kithyoma, 2003).

It is important to highlight that hydro and thermal power contribute a major share of global electricity generation (Renewable Energy Policy Network for the 21st Century (REN21), 2016). The structure of global electricity production shows that fossil fuels and hydropower contributed 76.3 and 16.6% of electricity, respectively. Nuclear power contributed 10.9% (Obser'Ever, 2013), and renewable sources contributed 23.7% (REN21, 2016). The dominance of fossil fuels on the structure of electricity production still persists to this day. However, the overwhelming scientific evidence is that the unfettered use of fossil fuels is causing the world's climate to change, with potential catastrophic effect (Bazmi, Zahedi, & Hashim, 2011). As such, the use of sustainable energy is a major global focus nowadays.

SSA accounts for 13% of the global population, but only 4% of global energy demand (IEA, 2014). The region is rich in energy resources, but they are largely undeveloped. Biomass is by far the most important renewable energy source in SSA. Yet SSA produces very little electricity from biomass sources. The IEA (2014) projects that power generation capacity in SSA will quadruple by 2040 and almost half of the growth in generation will come from renewable sources. The biomass resources in SSA include forests, agricultural residues, and municipal organic wastes.

This paper analyses the existing electricity production scenario in SSA. The focus is on disaggregating electricity production to show the contribution of biomass sources to the electricity production structure. The paper provides a trend analysis between 2003 and 2012 using data from IEA. Comparisons of the scenario obtaining in SSA are made with other regions in the world. The paper also highlights differences between regions in SSA in terms of use of biomass resources for electricity production.

Table 1. Examples of studies on availability of biomass resources in Africa

Study	Major findings	Conclusions	Researchers
Biomass and bioenergy supply from Mozambique	Production costs for eucalyptus ranged from 0.6 to 1.2 Euro GJ ⁻¹ varying from 7 to 25 t _{dm} ha ⁻¹ year ⁻¹ for arid to productive regions	Mozambique has the potential to generate up to 6.7 EJ year ⁻¹ with moderate use of agro-technology and using firm sustainability criteria	Batidzirai, Faaij, and Smeets (2006)
	The lowest delivery costs were 2.6, 3.2 and 6.8 Euro GJ ⁻¹ for pellets, pyrolysis oil and Fischer-Tropsch (FT) fuels, respectively, generated via circulating fluidised bed gasification		
	FT fuels from pellets and pyrolysis oil result in cheaper costs of 4.5 and 4.8 Euro GJ ⁻¹ respectively		
Potential of biomass energy for electricity generation in sub-Saharan Africa	Using 30% of agro-residues and 10% of wood forest residues, about 5,000 MW and 10,000 MW respectively can be generated in Africa	Biomass forms the bulk of energy use for cooking and other thermal uses, with low conversion efficiency in Africa.	Dasappa (2011)
A comprehensive review of biomass resources and biofuels potential in Ghana	Biomass including energy crops, crop and forest residues, urban wastes and animal wastes contributes 64% to the primary energy supply mix of Ghana	There is huge potential for biofuels production from the abundant biomass resources in Ghana	Duku, Gu, and Hagan (2011)
Current bioenergy production potential of semi-arid and arid regions in sub-Saharan Africa	Land availability for energy production ranges from 2% in South Africa to 21% in Botswana	It is important to research and invest in sustainable bioenergy production in semi-arid and arid regions of SSA as it has the potential to drive rural economic and social development.	Wicke, Smeets, Watson, and Faaij (2011)
	The technical potential of the eight countries is estimated at 300 PJ year ⁻¹ for cassava ethanol production, 600 PJ year ⁻¹ for jatropha biodiesel production or 4,000 PJ year ⁻¹ for fuelwood		
	Cassava ethanol, jatropha oil and fuelwood can compete economically with respect to energy sources		

2. Overview of biomass supply in SSA

Biomass is one of the largest renewable energy resources in SSA (Benoit, 2006; Karekezi & Kithyoma, 2003). It accounts for about 80% of the regional energy supply (Jingura & Kamusoko, 2016). One of the main important forms of biomass is wood which provides about 87% to the total biomass supply, either as a fuel or as wood products (Bildirci & Özaksoy, 2016). The biomass potential of Africa has been a subject of numerous studies. The primary origins of biomass are forestry, agriculture and various organic wastes. After realising paucity, as well as the poor quality of data available in Africa on biomass energy resources, Stecher, Brosowski, and Thrän (2013) conducted a literature review on studies about biomass resources in Africa.

In addition, Dasappa (2011) provides a good overview of biomass resources in SSA. There shall be no attempt in this paper to repeat the findings highlighted in these two studies. However, a summary of the studies related to estimation of biomass resources in Africa is presented in Table 1. The import of these studies is to substantiate the availability of biomass resources in Africa that can be used for energy purposes.

3. Structure of electricity production

3.1. General structure

The general structure of electricity production comprises renewable and non-renewable source. These are presented in Table 2. The structure shows the main sources of electricity production. As stated earlier, fossil fuels are the bedrock of global electricity production. Coal is the main hydrocarbon used in thermal power stations.

With reference to SSA, the majority of the countries produce their electricity from hydropower. Hydropower provides on average about 23% of SSA's annual electricity output (Obser'Ever, 2013). Biomass provides less than 2% in most cases. South Africa is the only country in the region with a

Table 2. General structure of electricity production

Non-renewable sources	Renewable sources
<ul style="list-style-type: none"> • Nuclear • Fossil fuels 	<ul style="list-style-type: none"> • Geothermal • Wind • Biomass • Solar • Hydro

nuclear sector. This nuclear sector in South Africa produces 3% of total electricity output in Africa. In Mauritius, the power sector has shifted considerably from complete dominance of fuel oil to coal and bagasse to generate electricity (Hassen & Bhurtun, 2005). About 54, 20 and 17% of the total electricity output was generated from fuel oil, coal and bagasse, respectively, while kerosene and hydro were minor contributors, in 2002 (Ramjeawon, 2008). Currently, approximately 44% (or 750 GWh) in Mauritius is obtained from sugar industry, with bagasse supplying 41% (or 360 GWh) of the electricity (Ramjeawon, 2008).

3.2. Total electricity net generation

It is important to provide a perspective of total electricity production in Africa. This will show the quantum of electricity produced in Africa as a continent. It will then be easier to disaggregate the total output and measure the contribution of biomass sources. Total electricity output in SSA in 2012 was 398.6 TWh (IEA, 2015). This represents a 24.6% increase between 2003 and 2012. This is an encouraging trend. Figure 1 shows the temporal trends in total electricity generation in North Africa and SSA over a period of ten years from 2003 to 2012. The data were provided by IEA (2015).

The average electricity generation in the four regions shown Figure 1 varied significantly between 2003 and 2012. The mean was 365 TWh, and ranged between 319.9 and 398.6 TWh in Southern Africa. In comparison, North Africa had a lower mean output at 218.3 TWh for the same period. The percentage increase in electricity output for each region were 72% for North Africa, 24.6% for SSA, 55.5% for SSA (excluding South Africa) and 10% for South Africa. These are marked differences. Noteworthy is that SSA (excluding South Africa) made significant gains in electricity output in the period under review.

The dominance of South Africa is quite clear in Figure 1. In the period under review (2003–2012), the country produced an average annual electricity output of 234.8 TWh (ranged from 217.2 to 245.6 TWh). This was more than all the other countries in SSA combined. SSA (excluding South Africa) produced a mean output of 130.2 TWh in a range of 102.7 to 159.7 TWh. This correlates with the more advanced level of development in South Africa compared to other countries in the region. South Africa derives over 70% of its primary energy from its large coal reserves. However, biomass plays a critical role as energy supplier mainly in South Africa. In addition, the country has high levels of renewable energy potential, particularly for wind and solar along the coastline (Energy Research Council, 2009).

To put dominance of South Africa into perspective, in 2012, South Africa produced 239 TWh, which was 60% of the total output of SSA. It is known that South Africa’s electricity output needs to be borne in mind when examining the electricity generating structure of SSA, as South Africa accounts for more than 60% of the region’s output (Obser’Ever, 2013). Hence the segregation of South Africa in Figure 1. It is also essential to further acknowledge that SSA (excluding South Africa) has the world’s highest “energy gap” and huge potential for renewable energy supply, yet the region is endowed with vast amounts of renewable energy and other forms of energy that can be explored.

Figure 1. Total electricity generation in Africa.

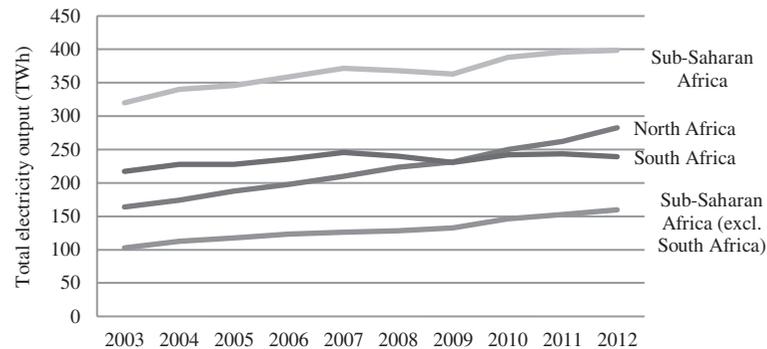
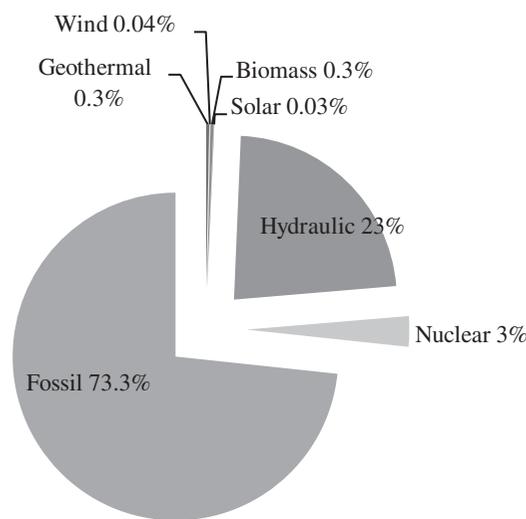


Figure 2. Structure of electricity production in sub-Saharan Africa in 2012 (Obser'Ever, 2013).

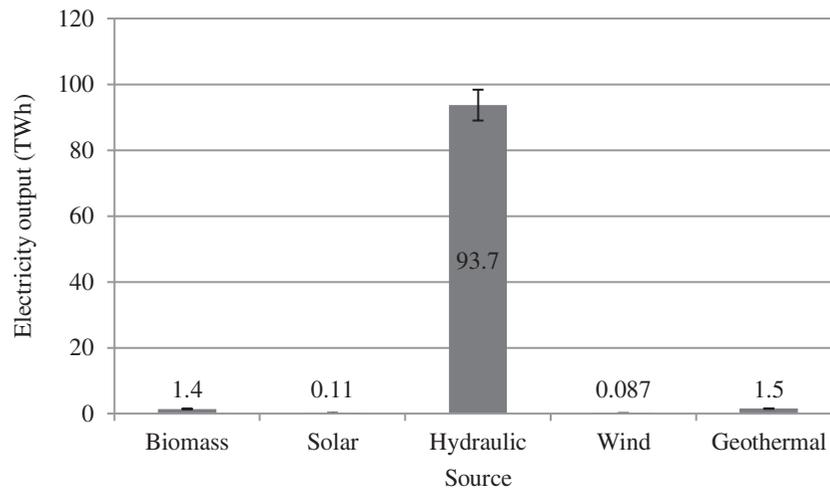


3.3. Structure of electricity production in SSA

The main sources of the electricity in SSA are fossil fuels and hydropower. Coal is the major hydrocarbon used for electricity generation in SSA. SSA has considerable reserves of coal, most of which are located in Southern Africa. Africa’s technically exploitable hydropower capability is estimated to be in excess of 1,917 TWh year⁻¹, representing about 13% of the global total (Soutar & Deaville, 2005). Using data obtained in 2012, the structure of electricity production in SSA is shown in Figure 2. It is worth pointing out that this structure for 2012 was not very different to that for the other years between 2009 and 2012. It gives a good representative of the temporal structure over the decade.

From Figure 2, it can be seen that renewable energy sources contributed 23.7% of the total electricity output in 2012. The bulk of this (23%) was from hydropower. A general conclusion from this observation is that biomass sources contribute very little to electricity production in SSA. However, there is extensive experience in the region for agro-based industries utilising cogeneration to meet their heat and electricity demands (Eleri & Eleri, 2009). At 0.3%, use of biomass energy for electricity generation is very low. The main obstacles to the development of large-scale biomass energy systems such as cogeneration and ethanol production in SSA include lack of awareness of their potential, de-industrialisation and rising plant closure, financial constraints, and lack of supportive investment framework (Eleri & Eleri, 2009). Taking East and Southeast Asia as a comparator region, in the same year (2012), biomass contributed 0.6% to total electricity output, giving a differential between the two regions of two times. However, the share of biomass contribution remains relatively small in both regions and awaits further development.

Figure 3. Structure of electricity production from renewable energy sources in sub-Saharan Africa for the period between 2009 and 2012.



3.4. Structure of electricity production from renewable sources

Focusing on renewable sources only, a specific structure can be constructed for electricity generation from these sources. The generation mix varies between the sources. The electricity production data for a 4-year period between 2009 and 2012 showed a considerable variation among the renewable sources in SSA. This can be used to measure the extent of electricity production from different renewable sources. The mean electricity production structure for a 4-year period (2009–2012) is shown in Figure 3.

Figure 3 shows that amongst renewable energy sources hydropower is the most dominant source of energy in SSA. The region’s mean annual electricity output from hydropower ranged between 85.1 to 99.4 TWh with a mean of 93.7 TWh. On the other hand, biomass (1.4 TWh) plays a limited role in electricity production in SSA. When analysed against the potential for electricity production from biomass sources, given as 100 TWh for the region (Dasappa, 2011), it can be seen that the gap between potential and reality is very big in SSA. Dasappa (2011) estimated that by using 30% of crop residues and 10% of forest residues, 100 TWh can be generated in SSA. At total electricity output in 2012, this would be 25% of total electricity generation. Langford (2014, July 10) ascribed the lack of advancement in sustainable use of biomass in SSA to lack of coordination and harmonisation between many players involved in the development, production, diffusion and trade of technologies and processes linked to biomass energy.

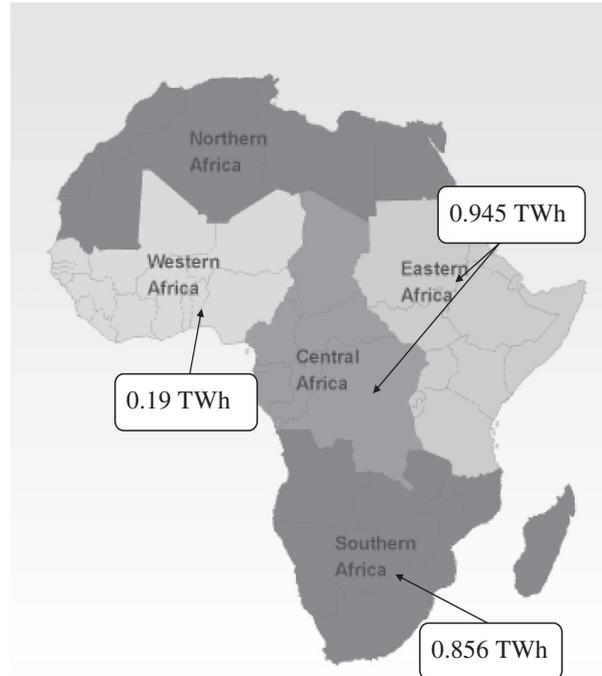
4. Regional comparisons in SSA

Africa can be divided into five regions. These are North, East, West, Central and Southern Africa. With the exception of North Africa, the other regions make up SSA. The regions of Africa are shown in Figure 4. There is no considerable use of biomass sources for electricity generation in North Africa. The bulky of electricity in North Africa comes from fossil fuels (International Renewable Energy Agency [IRENA], 2015). The mean electricity generation from biomass sources over the decade are presented in Table 3. There are significant differences among the three regions in the use of biomass energy for electricity generation.

Table 3. Regional comparisons in use of biomass energy for electricity generation in sub-Saharan Africa

Region	Mean value (2003–2012) TWh	Standard deviation
Southern Africa	0.74	0.06
East and Central Africa	0.89	0.05
West Africa	0.21	0.03

Figure 4. Regions of Africa and total electricity generation from biomass sources in 2012.



West Africa is conspicuous by its low levels compared to the other regions. There was not much year-to-year variation across all regions as shown by the standard deviations.

To illustrate the trends in electricity generation from biomass sources in SSA, a ten-year trend (2003–2012) is shown in Figure 5. From Figure 5 it can be seen that West Africa lags far behind the other regions in use of biomass sources for electricity generation. This observation is buttressed by data in Table 3. West Africa is highly dependent on fossil fuels and hydro for electricity generation (IRENA, 2015). The trend in West Africa actually declines between 2011 and 2012 from 0.23 to 0.19 TWh. Whereas in the other regions there is an increase from 2011 to 2012.

Disaggregating the data in Figure 5 by country provides a different perspective of the extent of use of biomass sources for electricity generation, on a country by country basis. This is useful for the purpose of understanding what is happening in individual countries. As there was very little year-to-year variation between 2003 and 2012, a ten-year average electricity output from biomass sources can be computed and used to measure the performance of each country. The data are presented in Table 4.

Figure 5. Trends in electricity production from biomass sources in sub-Saharan Africa.

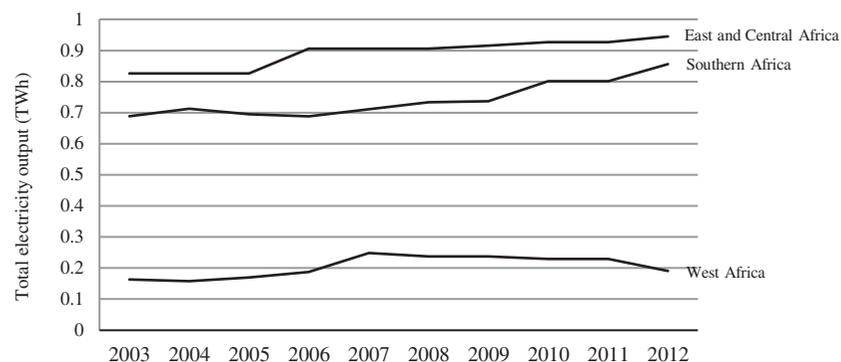


Table 4. Average electricity generation from biomass and waste in SSA from 2003 to 2012

East and Central Africa		West Africa		Southern Africa	
Country	TWh	Country	TWh	Country	TWh
Burundi	0	Benin	0.001	Angola	0
Chad	0	Burkina Faso	0	Botswana	0
Comoros	0	Cameroon	0.047	Lesotho	0
Congo (Brazzavile)	0	Cape Verde	0	Madagascar	0
Congo (Kinshasa)	0	Cote d'Ivoire	0.095	Malawi	0
Djibouti	0	Equatorial Guinea	0	Mauritius	0.463
Eritrea	0	Gabon	0.007	Mozambique	0
Ethiopia	0	Gambia	0	Namibia	0
Kenya	0.316	Ghana	0	South Africa	0.273
Rwanda	0	Guinea	0	Swaziland	0
Seychelles	0	Guinea-Bissau	0	Zambia	0
Somalia	0	Liberia	0	Zimbabwe	0.063 ^a
Uganda	0.063	Mali	0		
Tanzania	0.019 ^a	Mauritania	0		
Sudan	0.51	Niger	0		
		Nigeria	0		
		Sao Tome and Principe	0		
		Senegal	0.046		
		Sierra Leone	0		
		Togo	0.003		

Source of raw data: IEA (2015).

^aFigure for 2012 only.

It can be seen from Table 4 that only four countries in East Africa, six in West Africa and three in Southern Africa were producing electricity from biomass and waste sources. Most notable countries are Sudan (including South Sudan), Mauritius and Kenya. The case of Mauritius in terms of cogeneration in the sugar industry is well known. Mauritius generates about 40% of its electricity from sugarcane cogeneration (Dasappa, 2011). This could explain why access to electricity is 99% in Mauritius. That so many countries in SSA are not using biomass sources for electricity generation is made so conspicuous in Table 4.

Figure 5 also shows a slow rise in the trends for electricity production from biomass sources from 2003 to 2013. In fact, the actual percentage increases in output between 2003 and 2012 were 24, 14 and 17% for Southern Africa, East and Central Africa and West Africa respectively.

5. Key issues for use of biomass sources for electricity generation in SSA

Access to electricity is a major challenge in SSA. This point cannot be overemphasised. With access to electricity ranging from 52% of the urban population and as low as 8% in rural areas in SSA (Dasappa, 2011), probably biomass has a major role to play in increasing total output. The key issues are availability of technology and economics. Availability of raw materials is not a major issue as SSA abounds with vast sources of biomass material. In fact, the IEA Bioenergy Task 40 reports (Smeets, Faaij, & Lewandowski, 2004) that Africa has the largest bioenergy potential in the world. Though this is disputable, the fact remains that much more energy can be produced from biomass sources in SSA than is the case today.

Physical, biological and thermo-chemical conversion technologies are available for utilising biomass to generate electricity. These consist of direct combustion, gasification, pyrolysis, liquefaction,

Table 5. Typical capital costs and the levelised cost of electricity of biomass power technologies

	Investment cost USD kW ⁻¹	Levelised cost of electricity range USD kWh ⁻¹
Stoker boiler	1,880–4,260	0.06–0.21
Bubbling and circulating fluidised boilers	2,170–4,500	0.07–0.21
Fixed and fluidised bed gasifiers	2,140–5,700	0.07–0.24
Stoker CHP	3,550–6,820	0.07–0.29
Gasifier CHP	5,570–6,545	0.11–0.28
Landfill gas	1,917–2,436	0.09–0.12
Digesters	2,574–6,104	0.06–0.15
Co-firing	140–850	0.04–0.13

Source: IRENA (2012).

anaerobic digestion, fermentation and trans-esterification (Jingura, Musademba, & Kamusoko, 2013). Most of these are mature commercial technologies that are relatively not complicated to use. IRENA (2012) and Jingura et al. (2013) provide a good overview of these technologies. In order to leverage technology advances, SSA needs to invest in these technologies. IRENA has provided some investment costs for biomass power technologies. These are presented in Table 5.

6. Conclusion

The principal sources of electricity in SSA are fossil fuels (73.3%) and hydropower (23%). Between 2003 and 2012, a considerable temporal variation in the quantity of electricity generated from biomass in SSA has been observed. Thirteen SSA countries obtain their electricity from biomass sources. Significant spatial variations have shown that Eastern and Southern Africa generate more electricity from biomass sources than Western Africa. Biomass is the main traditional source of energy for many purposes in SSA. An estimated 80% of SSA's energy comes in form of traditional biomass. There is limited use of biomass for electricity generation in SSA mainly attributed to technical and economical issues. Several modern biomass conversion technologies to generate electricity are well-established and supported by continuous research and development. A large population in SSA has no access to electricity. This is a development issue for the region and more people should have access to electricity. Already in some countries in SSA, such as Mauritius, access to electricity is 99%. About 40% of electricity in Mauritius is generated from sugar cane cogeneration. That SSA abounds in biomass resources is in no doubt, equally valid is the fact that SSA can meet its electricity demand from biomass sources. The levels of investment required for this to happen are not astronomical and can be met by countries in this region.

Funding

The authors received no direct funding for this research.

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Citation information

Cite this article as: Temporal and spatial analysis of electricity generation from biomass sources in sub-Saharan Africa, Raphael M. Jingura & Reckson Kamusoko, *Cogent Engineering* (2017), 4: 1296757.

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