Bioenergy Efficiency Evaluation for Sustainable Optimization in Sub-Saharan Africa

Katundu Imasiku
[a] Africa Centre of Excellence in Energy for Sustainable Development,
College of Sciences and Technology, University of Rwanda,
Nyarugenge, 1109, Kigali, Rwanda.
kunduimasiku@gmail.com

Valerie M. Thomas
[b] School of Industrial and Systems Engineering, Georgia Institute of Technology, 755 Ferst Drive NW, Atlanta, GA 30332-0205, USA.
[c] School of Public Policy, Georgia Institute of Technology, 685 Cherry Street, Atlanta, GA 30332-0345, USA.
valerie.thomas@isye.gatech.edu

Abstract

Energy underpins economic growth globally regardless of the levels of development achieved this far. It is key to the production of food and water supply and other goods and services in sub-Saharan Africa (SSA) and globally. However, energy production and utilization and the interdependent economic activities, Agriculture, Forestry and Other land Use, results in high greenhouse gas (GHG) emissions. Using qualitative analysis, we evaluated the different primary energy sources within the energy supply chain network from generation, through its conversion to utilization to determine the energy efficiency and quantify the opportunity to mitigate these losses. We found that about 90% of the primary energy is lost through unsustainable conversion processes and only about 10% of the energy is utilized. Specifically, there is an opportunity for energy efficiency strategies to improve bioenergy capacity in SSA by about 40% on both the supply and demand side to reduce energy poverty and drive economic growth while transitioning to a low-carbon economy and climate-resilient energy sector, thereby enhancing sustainability and delivering universal and affordable energy access to all in SSA.

Keywords
Sub-Saharan Africa, Bioenergy, Efficiency, Energy supply-chain Network, Sustainability.

1. Introduction

The demand for energy in Africa is generally growing at double the global rate, and Africa's abundant renewables resources and decreasing technology cost has doubled the deployment of solar photovoltaics (PV) and other renewables on the continent. With this high demand for modern and more efficient energy resources, Africa has also become one of the world's major oil and gas markets. This tag-of-war between fossil fuels and renewable is not so easy to defeat with renewable resources (UNIDO, 2009).

Almost 50% of the African people (600 million people) did not have access to electricity by 2018, while around 80% of sub-Saharan African organizations endured successive power outages which lead to financial losses. Further, around 900 million people do not have access to clean cooking facilities and this has led to annual premature deaths of almost 500 000 people from biomass air pollution-related diseases (Imasiku, Thomas, & Ntagwirumugara, 2020). It also contributes to forest depletion resulting from unsustainable harvesting of fuelwood, as well as imposing a considerable burden and loss of productive time, mostly by women (IRENA, 2019; UNIDO, 2009).

The continent's aspiration to quicken a modern extension keeps on being hampered in numerous nations by unstable energy supply. Out of 56 countries in SSA, only a small number of countries - including South Africa, Ethiopia, Ghana, Kenya, Rwanda and Senegal – are succeeding in achieving full access to power by 2030. Solid biomass remains a primary fuel for cooking alongside clean cooking policies and this has reduced population growth because of premature deaths that are related to inhaling fumes from poor cooking facilities (Imasiku, Thomas, & Ntagrirumugara, 2019; Power People Planet, 2015).

In sub-Saharan Africa, the urban/rural electrification access rationale is approximately 60% to 14 % and yet 80% of the energy consumed is biomass. The main issue with the current programs is over emphasizing on energy access and yet energy efficiency is also another problem that results in significant socio-economic, health and environmental disadvantages (Papastefanakis, 2015). SSA uses more biomass (firewood and charcoal) much more than all other forms of energy combined and conjointly points to biomass efficiency as being a critical strategy to increase energy efficiency while addressing the health security issues presented by using poor or energy inefficient cooking methods (IEA, 2019). This study evaluates the bioenergy supply chain network concerning loss percentages and recommends energy-efficient strategy on how to realize the value for bio-energy.

2. Bio-energy Supply-Chain Network Method

The research aims to evaluate the bioenergy supply chain network of firewood harvesting and processing alongside its by-products like charcoal. In SSA almost around 900 million people still use the three-stone open fire or on simple wood or charcoal stoves which are not clean and inefficient (Energy Research Centre - University of Cape Town, 2015). The toxins released in form of smoke and greenhouse gases like carbon dioxide (CO_2) and methane (CH_4), that are also responsible for climate change. Since more than 500 000 premature deaths are recorded annually in SSA, from sicknesses with these toxins and particulate matter released, there is a need to reduce or completely eradicate these diseases or consequent deaths experienced. To achieve this, a threefold method based on supply chain assessment, bioenergy production loss determination is quantified in the supply chain network and finally propose some energy efficiency initiatives. Figure 1 shows the visual method adopted in this study.

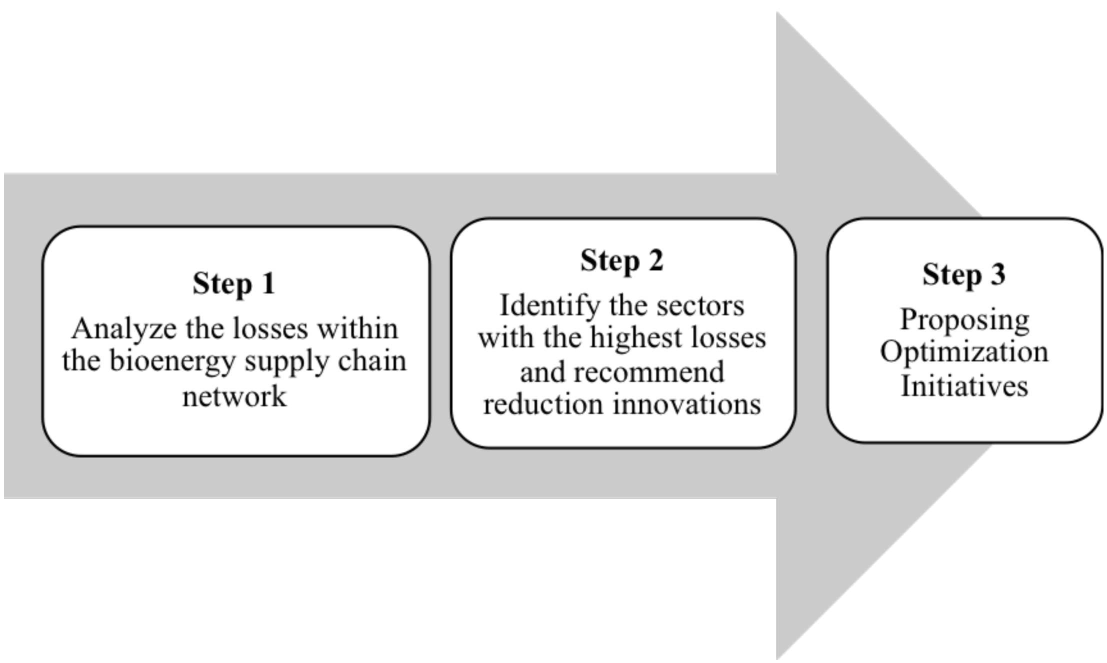

Figure 1. Steps for the research method

3. Results and Analysis

This research results will be categorized into two. First solid biomass will be analyzed using the traditional three-stone cooker and second it also analyzes the solid biomass through its conversion process to its by-product, charcoal as a fuel using inefficient traditional metal cook stove and finally initiatives are proposed at different stages of the supply chain network.

Step 1. Figure 2 evaluates the processing of solid biomass/ wood and how much losses are experienced between the supply and the demand side. Clearly, the use of solid biomass does not need any processing apart from cutting the wood, drying the wood and further chopping it into smaller logs. By the time it is used as a fuel, the thermal energy yield of the wood is still as high as 95%. Since the traditional three-stone stove has got zero-energy efficiency saving capacity, most of the energy is lost and only 12.4% is made available for cooking. This points to the energy conversion appliance on the demand side as being the target for energy efficiency innovation.

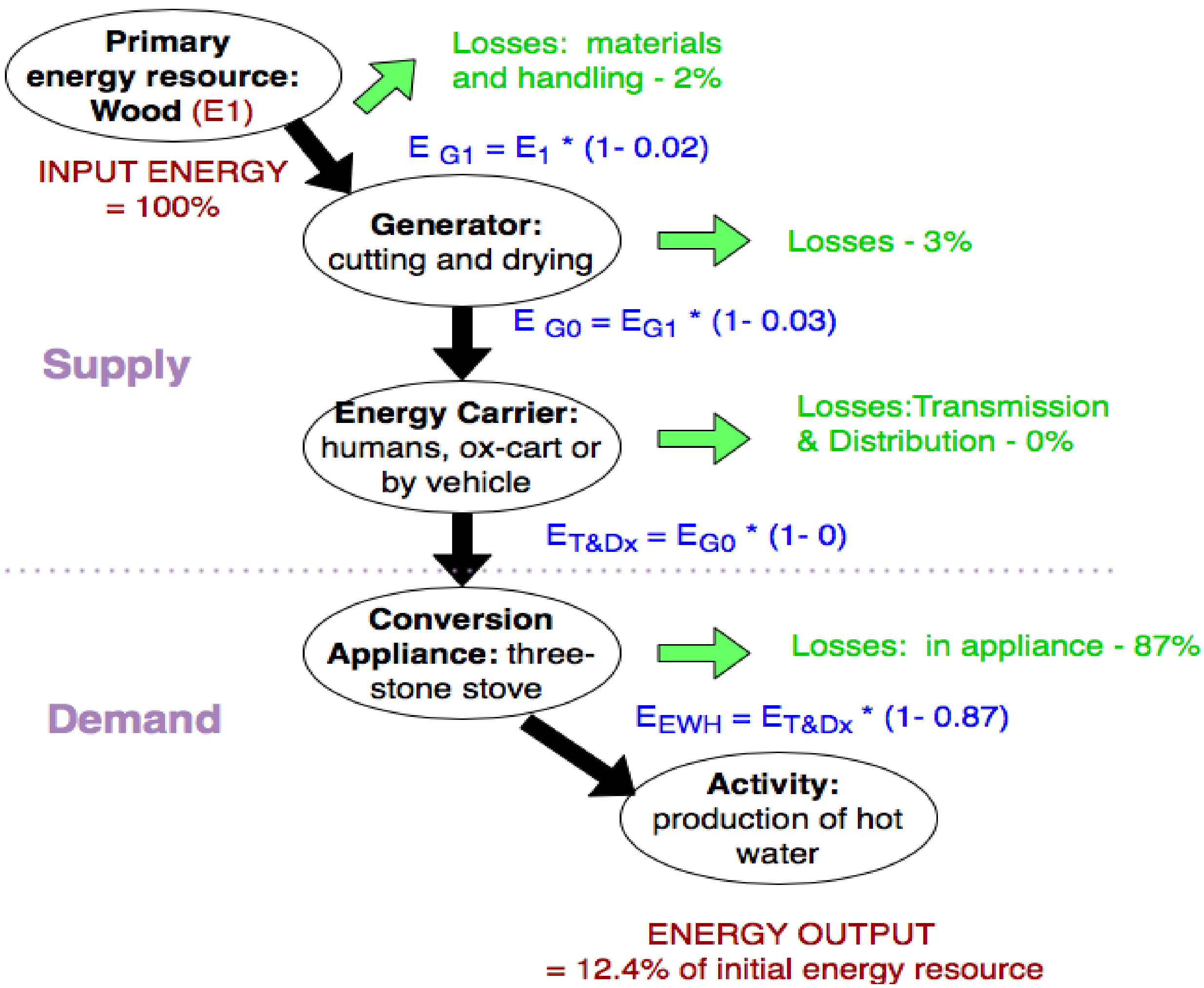

Figure 2. Solid biomass supply-chain network loss analysis

Step 2. Unlike the solid biomass energy in Figure 2, Figure 3 shows the charcoal supply chain network loss analysis undergoing some conversion process (Carbonization) in the Klin or Pit oven and this gives a thermal energy yield (useful energy) of 28% on the supply-side. Further, conversion losses are experienced by the conversion appliance at the demand-side of about 78% because the efficiency of the traditional metal inefficient cookstove used, is only about 12%, thereby leaving only 6% of the initial biomass energy resource as useful or available energy. The greatest losses incurred at the energy generator and energy convertor shows that there is a need for some energy efficiency initiatives at both the generator and the converter.

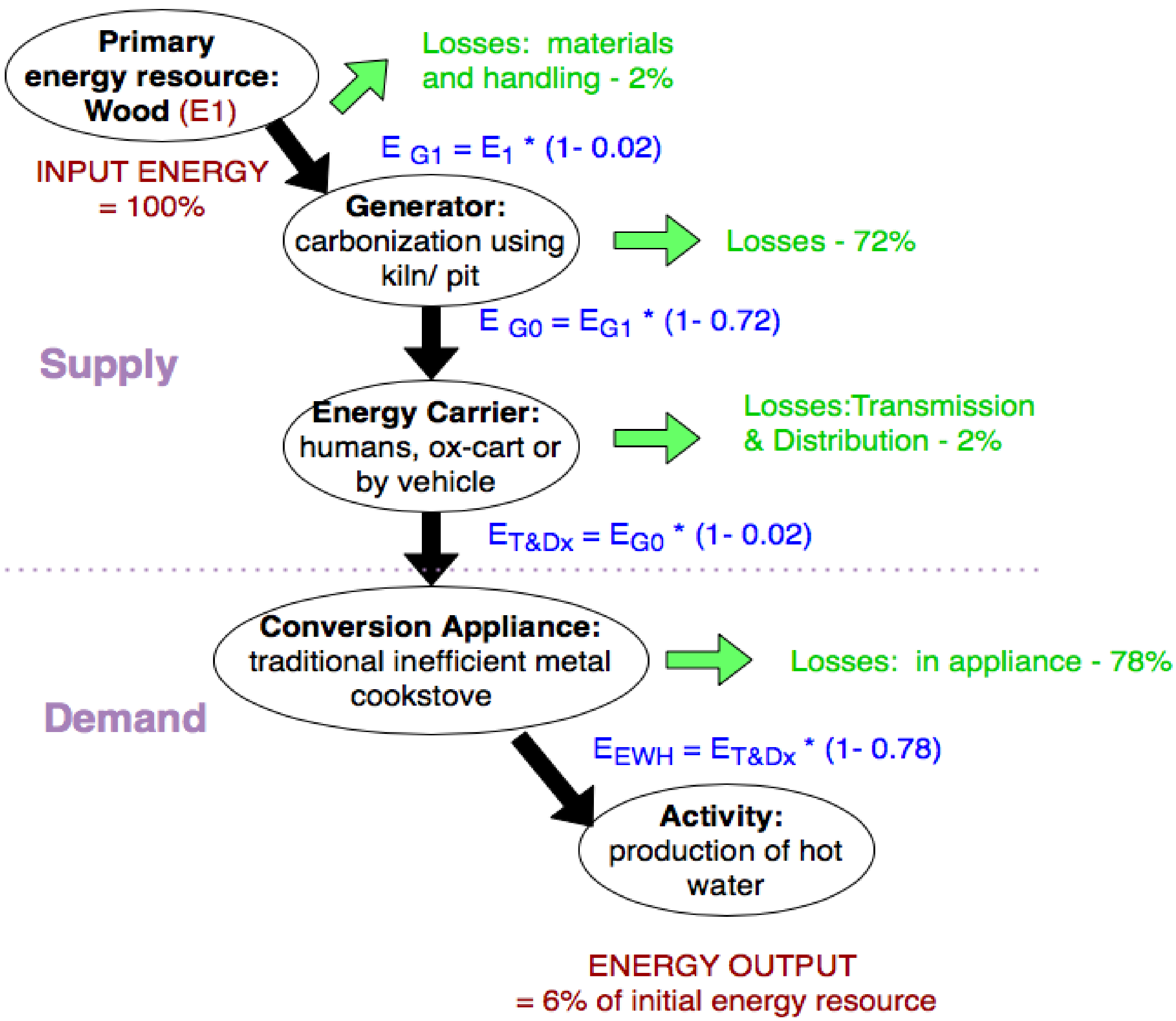

Figure 3. Charcoal supply-chain network loss analysis

Step 3. From step 1 and 2, it is clear that there is a need to first focus on the entire bioenergy supply chain network while prioritizing the sections that have high losses like the conversion appliances for both cases (Solid Wood and charcoal consumers) and on the energy generator in the case of the charcoal energy supply chain network. Currently, most researchers just focus on energy conversion processes. There is a need to also focus on some critical facts like: Despite carbonization causing a loss in energy as high as 72%, the end product, charcoal gives a higher yield in use than solid biomass (wood) with an average thermal energy yield of 8% and that of the three-stone African stove can go as low as 5% while the thermal energy of charcoal is about 28% (FAO, 1987; IRENA, 2019; Keita, 1987). The following are some of the initiatives that are proposed to improve the energy yield of biomass from the current 6% for charcoal and 12.4% for solid biomass available useful energy at the bioenergy conversion appliance:

i. The five significant areas of focus on financing optimal production supply and distribution of very high quality and high-performance modern cooking stoves that can be used by both wood and charcoal users. This will help in the transition to from dirtier/ unhealthy solid wood consumption to cleaner/ healthier charcoal and or even bioelectricity.
ii. modernizing the charcoal industry by addressing the huge losses incurred at the generation stage of charcoal production. Further, bioenergy can also be advanced and enhanced by promoting the production of bioethanol and biodiesel.
iii. make biofuel production feasible and affordable by increasing financial/ technical investment; previous studies by Winchester and Reilly show that lignocellulosic (LC) ethanol may become the major form of bioenergy if its production costs drops by 2030 (Winchester & Reilly, 2015).
iv. increasing power capacity with bioelectricity and build capacity and strengthen the leadership in biomass energy globally and especially in SSA.

While traditional metal charcoal stoves have about a 10-15% efficiency and incur heat losses of 85-90% (Energy Education, 2020), (https://energyeducation.ca/encyclopedia/Charcoal), the modern cook stoves with very high efficiencies of about 50% are still not affordable, accessible and guided by the right policies. Further analysis on a policy level can be obtained from the following table to guide policymakers on how to optimize the bioenergy resource for optimal efficiency in SSA (UNIDO, 2009).

In summary, although there has been some arguments as to which is a better way to consume biomass wood or charcoal? concerning waste or higher energy yield? Instead focus should be on a real energy balance, if the processes involved are sustainable or wasteful in terms of wood or charcoal usage. Further, there is a need to diversify to other energy sources to reduce bioenergy dependence and even compare the socio-economic impacts of selecting/ recommending one energy source over the other. Most importantly, there is a need to relook at charcoal generators by modernizing them so that they could emit fewer toxins and select a method that reduces the wastage while yielding more energy and sensitize the charcoal burners on the best carbonization practices.

Table 1. Sustainability factors for bioenergy feasibility analysis (IRENA, 2019).

Major benefits and good practice examples	Sustainable rural biomass supply			Biomass-to-energy innovations			Tools to enhance bioenergy sustainability		
	Sustainable feedstock supply	Affordability	Ecological soundness	Food security	Health promotion	Poverty alleviation	Energy transition	Local entre-preneurship	Strengthen resilience
1.1 Gender	✓	✓		✓	✓	✓	✓	✓	✓
1.2 Agro-ecology	✓	✓	✓	✓	✓	✓			✓
1.3 Nexus	✓	✓	✓	✓	✓	✓			✓
1.4 Breeding	✓	✓	✓			✓	✓		✓
1.5 FFS & FRG	✓	✓	✓	✓	✓	✓		✓	✓
1.6 Humanitarian	✓	✓	✓	✓	✓	✓	✓		✓
2.1 Briquettes	✓	✓	✓		✓	✓	✓	✓	✓
2.2 Cookstoves	✓	✓	✓		✓	✓	✓	✓	✓
2.3 Bioethanol	✓	✓	✓		✓	✓	✓	✓	✓
2.4 Biogas	✓	✓	✓	✓	✓	✓	✓	✓	✓
2.5 Heat & power	✓	✓			✓	✓	✓	✓	✓
3.1 Digitalisation	✓	✓				✓	✓	✓	✓
3.2 Entrepreneurship	✓	✓		✓		✓	✓	✓	✓
3.3 Tools	✓	✓	✓	✓		✓		✓	✓
3.4 REDD+**	✓	✓	✓	✓		✓	✓	✓	✓

* in relation to each section of this report

** REDD+: Reducing emissions from deforestation and forest degradation, along with enhancing forest carbon stock in developing countries

Table 1 shows the sustainability factors for bioenergy feasibility analysis matrix of major benefits and good practice examples against sustainable rural biomass supply, biomass-to-energy innovations and tools to enhance bioenergy sustainability.

4. Conclusions

Although Africa only contributes about 2% of the world's energy-related CO_2 emissions to date, it suffers disproportionately from the climate change effects alongside food insecurity, health risks and economic insecurity. Further, 80% of the consumed energy in SSA is solid biomass (wood) and in its transformed form (charcoal), of which only 12.4% and 6% are available useful energy for cooking. This gives energy efficiency strategies an opportunity to optimize the bioenergy resource in SSA on both the supply-side (Generator) and demand-side (Conversion Appliances). Optimal sustainable bioenergy use of energy at all stages of the supply/demand chain could reduce the negative impacts of energy consumption, while still allowing the same economic development, thereby enhancing sustainability and delivering clean and affordable energy access to all in SSA.

Acknowledgements

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Biographies

Katundu Imasiku is a seasoned engineer with expertise ranging from electrical engineering, telecommunications and infrastructure development and has extensive experience of more than 16 years in project management and leadership of energy, telecommunications and non-technical programs. He has interest in climate and energy efficiency, energy system modeling, life cycle assessments and industrial ecology and sustainability. He served in various positions, which include; Project Engineer, Protection and Design Engineer, Network Development Planner, Substation Design Engineer, Projects Manager and Operations Director in Zambia and South Africa. He holds a B Eng. in Electrical/ Electronics Engineering, an MBA and a PhD Candidate in Renewable Energy and several specialized certifications in Risk Management, Geographical Information Systems, Network Management, Solar and Photovoltaic Systems, Power Factory, Microgrid/Smart grids and MicroStation. He is a registered member of both the Engineering Institute of Zambia and Engineering Council of South Africa. Katundu is a 2018 JUAMI Fellow.

Valerie M. Thomas is the Anderson-Interface Professor of Natural Systems in the H. Milton School of Industrial and Systems Engineering, with a joint appointment in the School of Public Policy at Georgia Institute of Technology, USA. Dr. Thomas's research interests are energy and materials efficiency, sustainability, industrial ecology, technology assessment, international security, and science and technology policy. Current research projects include the environmental impacts of biofuels, and electricity system development. Dr. Thomas serve on the DOE/USDA Biomass Research and Development Technical Advisory Committee from 2013 to 2019. From 2004 to 2005, she was the American Physical Society Congressional Science Fellow. Dr. Thomas was a Member of the U.S. EPA Science Advisory Board from 2003 to 2009. She is a Fellow of the American Association for the Advancement of Science, and of the American Physical Society. Dr. Thomas received a B. A. in physics from Swarthmore College and a Ph.D. in theoretical physics from Cornell University.