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Jeremiah K. Kiplagat

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Combustion characteristics and Energy Potential of Municipal Solid Waste in Arusha City-Tanzania

Halidini Z. Sarakikya[1, 2*] and Jeremiah K. Kiplagat[1]
[1] Department of Energy Engineering, Kenyatta University.
P. O Box 43844 – 00100 Nairobi, Kenya.
[2] Department of Electrical Engineering, Arusha Technical College.
P. O Box 296, Arusha, Tanzania

ABSTRACT

Municipal Solid Waste (MSW) generation has been in the increase due to the population growth, changing life style, technology development and increased consumption of goods. The increase of waste generation may lead to environmental and social problems such as water contamination, land and atmospheric pollutions, provide breeding grounds for insects and rats, risk of fire, bad odors and potential cause of illnesses. The combustion properties and study of energy potential from municipal solid waste was undertaken. The energy flow (exothermic and endothermic) and thermal degradation analysis were carried out using differential scanning calorimetry and thermo – gravimetric analyzer respectively.

The sample of composition of municipal solid waste examined included papers, cardboard, wood, textile, rubber, polyethylene Teraphthalate (PETE), low density polyethylene (LDPE) and food waste. Composition of these materials were heated in a NETZSCH STA, 409 TGA apparatus and experiments were performed at heating rate of 10°C/min, in the nitrogen atmosphere at temperature between room temperature and 1100 °C. The thermal degradation characteristics of the MSW were obtained using thermo gravimetric analyzer (TGA) and derivative of thermo gravimetric (DTG).

It was observed that municipal solid waste is less reactive to combustion, but its reactivity can be improved through pre-treating process like drying, shredding and removing non combustible materials such as metals. Also pyrolysis and gasification can be used to convert MSW to gaseous fuel. The energy content of the solid waste tested was about 12MJ/kg. The elemental composition shows that Municipal solid Waste contains 50% and 5% of carbon and hydrogen respectively.

Keywords: Municipal Solid Waste, Thermal behavior, Thermo gravimetric Analysis

[1] Corresponding author. Tel.: +255 272503040. Fax: +255 272548337.
E-mail address: sarakikyazablon@yahoo.com

1.0 Introduction

The definition of municipal waste is used in different ways reflecting different waste management practices around the world. According to European Commission Environmental data Center on Waste [19], municipal waste consists of waste collected by or on behalf of municipal authorities, or directly by the private sector (business or private nonprofit institutions) not on behalf of municipalities. The bulk of waste stream originated from households, through similar wastes from sources such as commerce, offices, public institutions are also included.

Sources of MSW classifications are residential, institutional and commercial waste, where all these solid waste can be grouped into organic and inorganic [9]. Rural population of Tanzania produces less than 0.5kg/cap/day, where the main problem is the population living in urban and municipals which generate about 1.0 kg/cap/day [2]

The population in Arusha city has increased tremendously from 1,288,088 (2007 census) to 3,632,408 in 2012 which is on one hand is as a result of increased economic and tourisms activities. Arusha city has attracted people of different cultures and backgrounds and has accommodated those with relatively higher income as compared to other cities and region in Tanzania [1, 2,4,6].

Higher income cities generate more waste per capital than the lower income region and cities. [6, 7 8]. The above is true for Arusha, the main tourism city in Tanzania, where the amount of generated solid waste has increased from 137,000 tons per year in 2007 to about 386,340 tons per year in 2012, with a generating rate of 1.0 kg/cap/day [6].

The main method for solid waste disposal in Arusha is landfill, where any type of solid waste is dumped in an open area. There is no idea of energy recovery or recycling of the part of solid waste materials which can be used in other manufacturing process. According to [9], recovery is the part of solid waste management operation which prepares the waste material which is not useful for original user to be used in other manufacturing process or for other purposes. This study aimed to evaluate combustion characteristics and the energy potential of Municipal Solid Waste from Arusha for energy production. In order to achieve this purpose, the study focused to describe the characteristics of municipal solid waste from three different areas which are Ngarenaro, Sakina and Central market.

2.0 Material and Methods

2.1 Methodology

The methodology consisted of sampling and selection, sorting and laboratory analysis to determine the chemical and physical properties of municipal solid waste of Arusha city. The method of sampling was based on ASTM D5231 namely random truck sampling and quartering [9]. In this study, trucks as the one in the picture of figure 1 were used to carry the wastes collected and transfer to the dump site, where sorting and sampling was conducted. Wastes were randomly collected from different collecting places of central market, sakina and Ngarenaro markets within the Arusha as shown in figure 2. .

Figure 1: One of the trucks carrying MSW from the city to the site

Figure 2: Two different collecting point at Ngarenaro market

The random track sampling is shown in the flow chart of figure 3.The wastes were sorted and weighted by using weighing balance and then separated according to defined classification such as plastics, glass, paper, food waste and metals. The non-combustible wastes were removed from the rest of the wastes. The combustible waste was availed for analysis in accordance to the method developed by [9]. In order to accurately determine the waste composition an average weight of about 200kg of municipal solid waste was taken. This was as assumed to be a good representative of the total municipal solid waste composition at each collecting points under this study. The samples were subjected to standards test methods of proximate and ultimate analysis in accordance to ASTMD3172 and ASTM D3176 respectively.

The thermal degradation analysis was studied under Nitrogen condition using a thermo gravimetric analyzer type NETZSCH STA 409 PC Luxx connected to power unit 230V, 16A. High purity nitrogen, 99.95% used as carrier gas controlled by gas flow meter was fed into the thermo gravimetric analyzer with flow rate of 60ml/min and a pressure of 0.5 bars. In the STA 409 PC Luxx, proteus software was utilized to acquire, store and analyze the data.

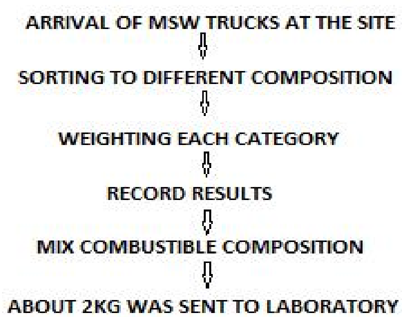

Figure 3: Flow of random truck sampling

2.2 Sample preparation

The samples were shredded into smaller pieces of approximately 30mm size, mixed and grounded in a grinding machine to less than 1mm size, this is in order to increases surface area of the sample that will allow easier penetration of heat [10,11]

Then a sample of 30±0.1 mg with average particle size less than 1mm was loaded to crucible and subjected into furnace and heated from room temperature to 1100°C, at heating rate of 10°C/min. The heating rate variation changes the peak temperature of the decomposition, as the heating rate increased, the peak temperature also increased [11]. The calculated thermo-gravimetric output from proteus software was obtained as thermal decomposition profile; thermo-gravimetric (TG), differential thermo-gravimetric (DTG) and differential scanning calorimetry (DSC) curves.

The heat released and absorbed by the municipal solid waste degradation was determined from the differential scanning calorimetry curves. The DSC monitors heat effect associated with phase changes transitions and chemical reactions as a function of temperature [11]. The heat was determined by calculating the area between the baseline and the curve. The heat can be positive or negative. When the heat is positive the process is endothermic and when the heat is negative the process is exothermic [11].

3.0 Result and Discussion

3.1 Proximate and ultimate analysis

The results of proximate and ultimate analysis are shown in Table 1 & 2. The moisture content of the municipal solid waste as received ranged between 55.70 and 63.99 wt. %, which is more than 50 wt. % of the total weight of the sample. This high moisture content is prohibitive for combustion process as it rises the ignition temperature, also its contents reduces the calorific value of the fuel [13], the moisture could be reduced by drying. The volatile matter released on dry mass basis of MSW for Ngarenaro, Sakina and Central market were 74.43, 84.00 and 78.31 wt %, respectively. This compares well with the volatile matter contained in pure biomass such as forest residue, oak wood, and pine which are 79.9, 78.1 and 83.0 wt. % respectively [16].
Generally, solid wastes which contain high volatile, have low fixed carbon, the case is same for the municipal solid waste from sakina which has volatile matter of 84.00 and fixed carbon of about 6.00 wt. %, compared to that of Ngarenaro and Central market. The advantage of high volatile and low fixed carbon is rapid burning of a fuel, while a fuel with low volatile and high fixed carbon like coal need to be burned on a grate as it take long time to burn out, unless it is pulverized to a very small size [15].
Therefore based on the value of volatile matter and fixed carbon it shows that the municipal solid waste is combustible. The ash content ranged between 3.29 to 5.97 wt. %, which is low, and is advantageous for waste management and the environment because of the possibility of having small quantities of heavy metals, salts, chlorine and organic pollutant [11]. The ultimate analysis of the municipal solid waste shows that the concentration of phosphorus and chlorine are negligible, the carbon and hydrogen content were above 50% and 5% respectively. The oxygen content was more than 34%. Sulfur content was about 0.29%, which was low compared to those of bituminous coal which is 1.1 wt. % [13].

Table 1: Proximate analysis of municipal solid waste from different areas of Arusha City

Location	Moisture of received MSW	Volatile (wt%) dry basis	Ash (wt%) dry basis	Fixed Carbon (wt%)	HHV (MJ/kg)
Ngarenaro	59.67	74.43	8.16	17.41	11.00
Sakina	63.99	84.00	10.00	6.00	11.37
Central Market	55.70	78.30	13.48	8.22	12.7

Table 2: Ultimate analysis of municipal solid waste from different regions of Arusha City

Location	C (wt %)	H (wt %)	O (wt %)	N (wt %)	S (wt %)	Cl (wt %)	P (wt %)
Ngarenaro	55.57	5.38	34.88	2.09	0.31	0.04	0.10
Sakina	55.70	5.29	34.27	2.13	0.22	0.07	0.13
Central Market	53.20	5.24	34.71	2.86	0.37	0.04	0.11

3.2 Calorific Value

The average calorific value of the municipal solid waste from Arusha city was 12 MJ/kg. This value is about 30% of energy contained in coal and lower than or about 60% of the average calorific value of biomass which is about 17MJ/kg [16,13]. This means energy release during combustion of MSW is lower as compared to biomass combustion. This means that one needs to burn larger amount of MSW to get the same amount of energy. The energy content of MSW can be improved by pre-treating the MSW so as to reduce the amount of oxygen, since oxygen reduces the energy content of a fuel [11]. The MSW can also be co-fired with coal for improving energy content [16]. Other processes to improve energy content of MSW are pyrolysis, gasification or torrefaction, which are used to produce bio-oil, syngas and char, respectively.

4.0 TGA Curves

Thermo-gravimetric Analysis (TGA) is a reliable and widely used laboratory technique employed to study the extent of mass changes due to volatilization and combustion of fuel components, and in addition allows great flexibility in controlling the composition of the combustion gases. The municipal solid waste tested degraded from79 to about 88 wt. % in the thermo gravimetric analyzer as shown in figure 4. In this case, the MSW have been burned in their mixed state, therefore it is important to study the combustion characteristics of the mixed waste. The curves of figure 4, give the burning temperature of the mixed MSW, and from the figure it is seen that the burning temperature of MSW of Arusha city is around 600 $^{\circ}$C.
The MSW from the Central market degraded by 88 wt. %, while those from Ngarenaro degraded by 79 wt. %. The residue formed ranged between 21 and 34 wt. %. These residues contain fixed carbon and ash. The high amounts of residues were observed in MSW from Ngarenaro 18.54 wt. % whereas those from the Central market and Sakina had lower amount of residues of about 13.95 wt % and12.89 wt % respectively. The char available in the residues can be used as a fuel, however, MSWs which have high ash content hinder the combustion of char due to the layer of ash which is formed on the surface which inhibits the diffusion of oxygen into the char [17].

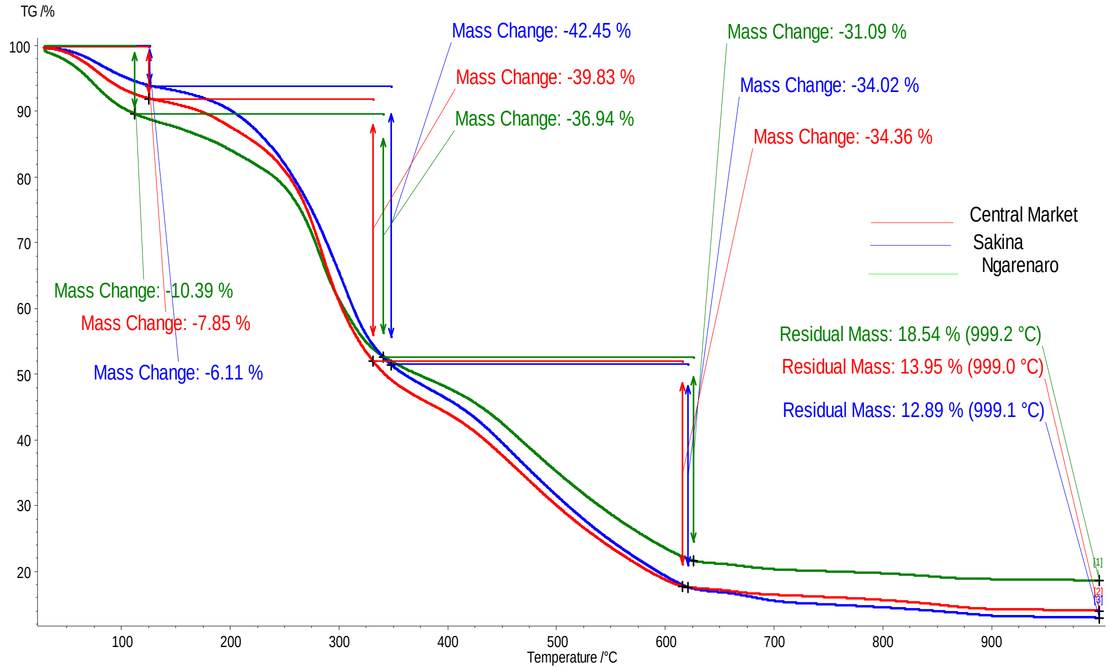

Figure 4: TGA graphs of Municipal solid waste from three locations in Arusha city

4.0 DTG curves

Derivative Thermo-gravimetric Analysis (DTG) is the analysis which gives the trend of reactivity of particles with the increase of temperature in the furnace. The point of the burning profile in which the maximum weight loss comes about due to the combustion is called peak temperature. This point is considered as an indicator of the reactivity of the sample. Another purpose of DTG is to assist in understanding of chemical reactions occurring in the furnace, combustor design, temperature profile of the combustion chamber, retention time and giving information on the change of mass and volume of the MSW as it travel down the grate.

Figure 5 shows the derivative of thermo-gravimetric analysis (DTG), which has four visible zones; these are moisture release zone, lignocellulosic degradation zone, plastic degradation zone and char pyrolysis zone [18]. The same identified regions were also observed by [13]. In the figure therefore, thermal destruction of solid waste is accomplished in four phases. The first phase is the drying phase which occurs in the initial heating of the solid materials. Here moisture is driven off as the materials are heated past the vaporation temperature of water and in this case of is around 150 °C. The second phase is the volatilization of vapors and gases which occur as the temperature of the waste continues to rise. Vapors and gases diffuse out as their respective volatilization temperature are attained. Here exothemicity property is shown by the waste materials as they are releasing out energy, and temperature is around 380 °C to 640 °C.

The third phase in the burn down of solids is the in place oxidation of the burnable solids left after the vapors and gases have been volatilized where the temperature is between 640 °C to 900 °C. The fourth phase in the process involves the final burn down of char and the consolidation and cooling of the inert residues known as ash, the temperature being higher than 900 °C. Generally in this case, figure 5 gives the trend of reactivity of the Arusha MSW with temperature.

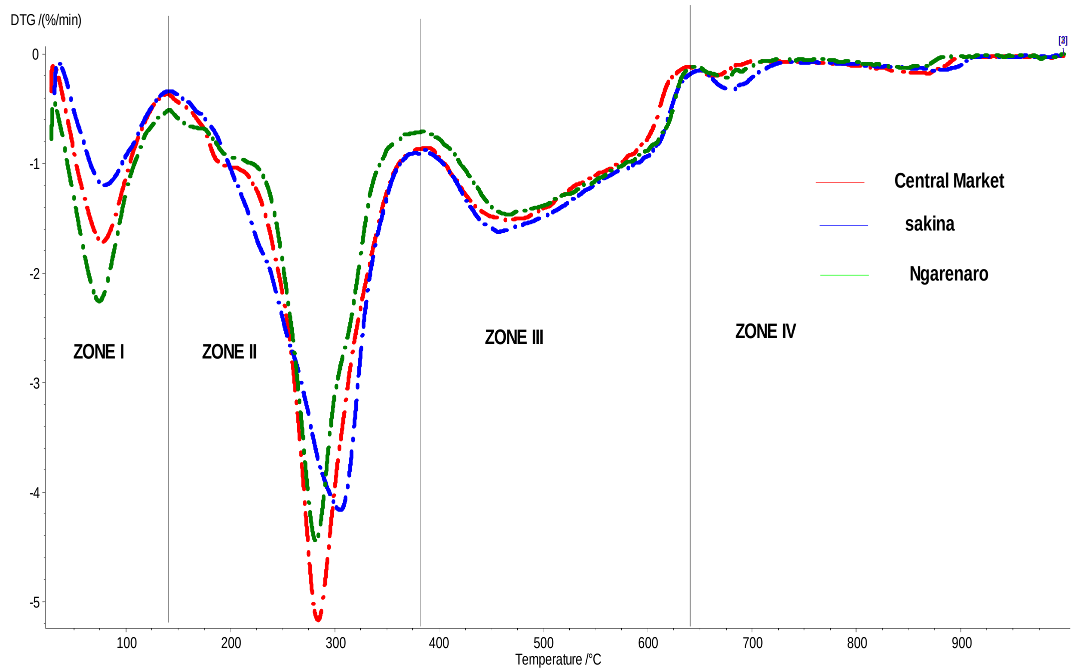

Figure 5: DTG of municipal solid waste from three locations in Arusha City

6.0 Conclusion

This paper presents the finding of municipal solid waste characterization of in Arusha city. The solid waste from three regions within the city (Arusha) was analyzed to determine their potential for energy recovery. The ultimate analysis of the waste showed that the waste contains more than 50% and 5% of carbon and hydrogen respectively which may contribute to high calorific value of Arusha municipal solid waste. The average percentage amount of nitrogen, sulfur, chlorine and phosphorus in the waste were 2.36, 0.3, 0.05 and 0.11 respectively which is low, which will lead to low emissions during combustion of the waste.

The average energy content of waste as measured by using a bomb calorimeter was 12MJ/kg this is about 30% of energy contained in coal and 60% of energy containing in other biomasses. Devolatilization zone is that zone where the temperature of the particles is greater than the temperature of the environment and is where the particles release energy. The municipal solid waste shows exothemicity property at the devolatilization zone. The devolatilization zone shows that the municipal solid waste can be easily ignited at temperature above 380 °C. Therefore municipal solid waste has a good potential to be used as a fuel.

7.0 Acknowledgements

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Experimental approach in performance optimization of a silica-gel/LiCl-water adsorption chiller using heat recovery mechanism

[1]Fred .T. Ishugah, [2]Ruzhu Wang, [2]Liwei Wang, [1]Jeremiah .K. Kiplagat
[1]Department of Energy Engineering, Kenyatta University, P.OBox 43844-00100, Nairobi, Kenya
[2]Engineering Research Center of Solar Power and Refrigeration Energy, School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
Email: Ishugah.fred@ku.ac.ke

Abstract:
This paper presents a new adsorption chiller system improvement based on the heat recovery mechanism. Experimental results showed that the cooling capacity and the coefficient of performance COP can greatly be improved through a set of modest control mechanisms. The results further showed that moderately short heat recovery time provides the best performance results (i.e. cooling capacity and COP) as compared to very long heat recovery time. However, longer heat recovery process coupled with longer cycle time leads to re-adsorption process which is significantly important in saving energy used in heating the hot water. Four main aspects have been considered to outline the significance of optimizing the heat recovery process; cooling capacity, COP, re-adsorption and the driving energy. As compared to other systems, this new system could achieve a COP of as high as 0.65 and a cooling capacity of about 3700Watts, which is a great improvement in the chillers performance.

Keywords:
Composite Adsorbent, Coefficient of Performance (COP), Specific Cooling Power (SCP), Mass Recovery, Heat Recovery

Introduction

Adsorption refrigeration has been considered to be a promising technology to cut down on the energy consumption and reduce CO_2 emission(El-Sharkawy, Saha et al. 2008). The use of low grade heat, ranging from 60^oC to 150^oC makes it possible to employ solar thermal or waste heat to power adsorption refrigeration systems. Compared with an absorption system, the adsorption cooling system has the advantages of mechanical simplicity and high reliability. As a result, it has been attracted much research attention in recent years. For these reasons, research and development of sorption systems have been intensified (Wang, Ge et al. 2009).

The main challenges still affecting development of adsorption cooling technology still lies on its low coefficient of performance and relatively low cooling capacity which are mainly affected by adsorption/adsorbate properties, configuration parameters and operating conditions (Liu and Leong 2005). In recent years, various heat and mass transfer models have been studied to improve the thermal performance in terms of the coefficient of performance (COP) and specific cooling power (SCP) of adsorptive cooling systems.

Until now, a lot of research work has been done on adsorption refrigeration technology. Wang(Wang 2001) and Sumathy et al. (Sumathy, Yeung et al. 2003) reported theoretical and experimental investigations done in various adsorption cycles in the past 2-3 decades. Saha et al.(Saha, Boelman et al. 1995), Chua et al.(Chua, Ng et al. 1999), and other researcher have done substation research work on computer simulation of adsorption refrigeration systems to optimize the performance and better understanding of the systems. Both the experimental analysis (Boelman, Saha et al. 1995) and the simulation models (Saha, Boelman et al. 1995, Chua, Ng et al. 1999) showed that there exists an optimum cycle time for the refrigerating capacity, but the COP increases monotonically with increase of the cycle time at a certain period of time. Excessively short cycle time leads to a lower cooling capacity and COP, and excessively longer time may also cause very low performance of an adsorption chiller. Fan et al.(Fan, Luo et al. 2007) did a review on solar and waste heat powered adsorption cooling and revealed that solar and waste heat utilization in adsorption cooling can meet the demand for energy conservation and environmental protection.

Although a number of different adsorption cooling systems designs and working pairs have been proposed and developed by many researchers, their performance enhancement is inevitable to realize full commercialization and widespread in use. Other than improving the system performance through accurately determining the adsorption characteristics and kinetics of the adsorbent–adsorbate pair, it is likewise essential to determine best operating conditions of the adsorption chillers. Despite the fact that the cycle time, heat transfer fluids temperature, and, heat and mass transfer time being the main operating conditions, with considerably higher effect on the adsorption chillers performance, heat recovery/transfer time effects are scarcely reported in the literature.

This paper presents operation strategies to improve the COP and the cooling capacity for a two bed adsorption chiller with composite adsorbent, sorbent of Silica Gel impregnated with Lithium Chloride, paired with methanol as the adsorbate.It analyses the effect of heat transfer fluids inlet temperatures, adsorption and desorption cycle times and the heat recovery time on the performance of the chillers and concludes by proposing the best operating conditions.

System description

Experimental set-up

The experimental system was set up as shown in Fig 1. The system basically consisted of hot water cycle, cooling water cycle, and chilled water cycle. Hot water, the chillers driving heat source, was supplied by an electrical boiler at a set constant temperature. Cooling water, used to remove condensation and adsorption heat from the chiller, dissipated the heat gained from the chiller into the river water, through a heat exchanger. Chilled water, obtained due to the cooling effect, was taken to a chilled water storage tank in which a set of electric heaters were installed to balance the cooling with heating load. Meanwhile, a fan coil unit was used in parallel to output cooling to the ambient. Hot, cooling and chilled water temperatures inlets and outlets at the chiller were collected by the data logger using temperature sensors. The mass flow rates for hot, cooling and chilled water cycles were measured at their respective chiller inlet points.

Chiller description

Many adsorption chiller designs are now available. Despite the fact that they might be using different working pairs, they both exhibit similar structures and working process. The two bed composite adsorbent paired with water or methanol chiller is composed of three chambers as shown in Fig. 1. Two vacuum chambers are similar to each other with each comprising of an adsorber bed (heated by hot water from the electric boiler or cooled by cooling water from the cooling tower), a condenser (cooled by cooling water) and an evaporator (providing media for heat dissipation through condensation of refrigerant from the heat pipe evaporator). The third chamber (gravitational heat pipe) contains a heat-pipe evaporator, providing surface of heat exchange between chilled water and methanol or water. Switching of the valves, which are controlled electronically apart from the one way valve, makes the adsorber bed to undergo alternate adsorption or desorption depending on the direction of the hot water and cooling water cycle in the chiller. A unidirectional electrically mass recovery valve installed between the two identical vacuum chambers to improve the performance and adaptability of chiller to a low temperature heat source through mass recovery process.

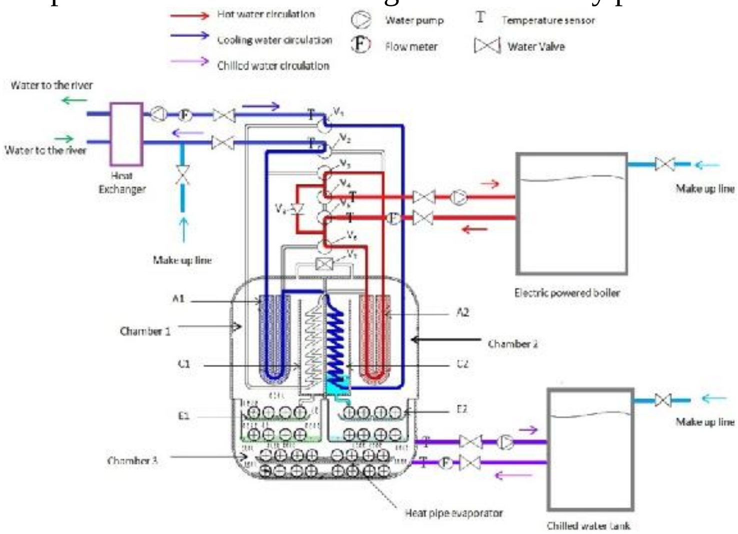

Fig.1 A schematic diagram of experimental set up(Ishugah, Wang et al. 2014)

A1-Adsorber 1, A2-Adsorber 2, C1-condenser 1, C2-condenser 2, E1-Evaporator, and, E2-Evaporator 2, V_1, V_2, V_3, V_4, V_5, V_6, V_7, and V_8 are process control valves of the chiller.

Operation mechanism

During operation, each cycle goes through heating and cooling, and mass and heat recovery processes in a systemic opening and closing of the valves as follows:

Heating/cooling time

Hot water flows into adsorber 2, providing the heat that desorbs the refrigerant. The desorbed the refrigerant condenses at condenser 2 and drips into evaporator 2, as the refrigerant condensate. At the same time, cooling water flows from condenser 2 through to adsorber 1. The cooling water carries away the heat of condensation of condenser 2 and cools down the adsorber 1 to the adsorption temperature.

Due to the heating process of the adsorber bed in chamber 2, evaporator 2 is heated by condensates of the refrigerant desorbed from adsorber 2, therefore providing no cooling effect. On the contrary, adsorber 1 adsorbs the refrigerant vapor enhancing evaporation outside the tubes of evaporator 1 leading to cooling effect at evaporator tube surface. The cooling effect by evaporating the refrigerant outside the tubes of evaporator 1 condenses the refrigerant vapor from heat pipe evaporator inside evaporator 1. The refrigerant condensate, inside tubes of evaporator 1, flows back to the heat-pipe evaporator where it evaporates resulting in the production of cooling capacity.

Mass recovery process

In this process, valve V_7 opens at the beginning of mass recovery process to connect chamber 1 and chamber 2 then closes at the end, contributing to re-desorption and re-adsorption that improves the chiller performance. During this process, the adsorbate at high temperature and pressure from the desorbing bed flows into the adsorbing bed at high speed. The adsorbing bed continues to adsorb and the desorbing bed continues to desorb till the pressures of the two chambers become the same.

Heat recovery process

The main purpose of this process is to recover the hot water used to heat the adsorber bed instead of wasting it when the adsorber switches from desorption to adsorption. Heat recovery is achieved by first rotation of valves V_4 and V_5, which bypasses hot water from the chiller, then valve V_1 and V_2, for preheating (to reduce heat needed to heat up) and pre-cooling (to improve performance) respectively. Heat recovery process proceeds with rotation of valves V_2 andV_3, and the half cycle completes by rotation of valves V_5 and V_6. As the last half cycle begins, adsorber 2 undergoes adsorption process while adsorber 1 undergoes desorption process by repeating similar steps on different bed.

2.3.4 System performance equations

The system performance of an adsorption cooling unit is measured mainly by the following two parameters, (i) COP, the coefficient of performance and (ii) SCP (W/kg of the dry adsorbent), specific cooling power. The COP and SCP can be estimated by the following equations:

$$\text{COP}=\frac{Q_{eva}}{Q_{in}} \tag{1}$$

where: Q_{eva} is the heat energy extracted from the evaporator and Q_{in} is the heat energy input during a half cycle.

$$\text{SCP}=\frac{Q_{eva}}{M_{ads}} \tag{2}$$

where: M_{ads} is the mass of the composite adsorbent in kg.

The energy input, Q_{in}, during a half cycle can be measured as:

$$Q_{in}=\dot{m}_w c_w \int_0^t (T_{hot,in}-T_{hot,out})dt \tag{3}$$

where: $\dot{m}_w$, is the mass flow rate of water, c_w, is the specific heat capacity of water, t, is the half cycle time, $T_{hot,in}$ and $T_{hot,out}$, is the hot water inlet and outlet temperatures respectively.

The heat extracted from the evaporator is calculated as:

$$Q_{eva}=\int_0^t \left[L_{wv}(T_{eva})-c_{ref}(T_{cond}-T_{eva})\right]M_{ads}\frac{dq}{dt}dt \tag{4}$$

where: L_{wv} is the latent heat of the refrigerant (Methanol), T_{eva} and T_{cond}, are evaporator and condenser temperatures, c_{ref}, is the specific heat capacity of methanol, and, q, is the concentration.

Results and discussion

Adsorption refrigeration cycle of this chiller is designed for utilizing low grade heat, which was selected to vary between 60^{o}C to 95^{o}C. The standard hot water temperature has been considered as 83^{o}C, as the COP was the best at this temperature level. In this analysis, the effect of operating inlet hot water temperature, hot water flow rate and cycle time on the performances is presented and discussed.

It is important to report that all the temperatures, the mass flow rates and the time durations, given and used in some computations, might be associated with experimental and computational errors. The temperatures provided were taken using temperature sensors (PT100, 4-wire system with accuracy standard A) and recorded by a data acquisition unit (Agilent 34970A). The temperature sensor has an absolute error of ±0.3^{o}C while data acquisition unit has an accuracy of

0.004%. The mass flow rates of the hot water, chilled water and cooling water were all measured using flow-meters with accuracy of 0.5%. The absolute error in measuring the mass of the adsorbent material is ±0.1kg. The specific heat capacity of water was considered as a constant number, and taken as $4200Jkg^{-1}K^{-1}$. The largest possible relative error in temperature measurementsas a result of the instruments used is 0.02, while that of the SCP and COP are about 0.2 and 0.15.

3.1 Adsorption/desorption duration

Figure 2 shows how the specific cooling power and the COP varies with the chillers set adsorption/desorption duration. Both the SCP and the COP increased with increase in adsorption/desorption duration until they got to their maximum, where optimal adsorption/desorption degree is reached, with SCP reaching a maximum of about 400 Watts/kg at a half cycle time of about 720 seconds while COP getting as high as 0.65 at adsorption/desorption duration of about 780 seconds.

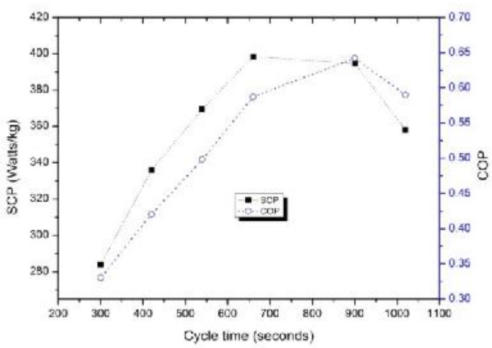

Fig. 2 Variation of SCP and COP with adsorption/desorption duration

Average inlet hot, cooling and chilled water temperature was set at 83°C, 22°C and 15°C, respectively, with the standard mass flow rates of hot, cooling and chilled water maintained

After the optimal adsorption/desorption degree is reached, further increase in half cycle time resulted in decrease in the chillers performance since the adsorption capacity falls due to saturation effect of adsorbate on the adsorbent matrix. Based on the experimental results, the highest COP and cooling capacity can be obtained at an adsorption/desorption duration of between 700 seconds and 800 seconds.

Heat recovery duration

3.2.1 Temperature profile characteristics with different heat recovery durations

Figure 3shows the outlet temperature characteristics of the hot water and cooling water under different heat recovery time. At the beginning of heat recovery process, hot water inlet is bypassed while cooling water is forced into the adsorber that is ending the desorption process. Hot water is then forced into the adsorbing adsorber, which is almost switching to the next desorption process, at the end of the heat recovery process. As the heat recovery process begins, cooling water temperature rises sharply due to the high temperature of the adsorber bed completing desorption process while the hot water temperature drops sharply due to the low temperature of cooling water in the adsorption bed tubes and low temperature of the other adsorber bed. The degree of temperature drop for hot water and temperature rise for cooling water varies depending on the heat recovery time as shown in Fig. 3. When the heat recovery time is shorter, the degree of temperature drop at hot water outlet as well as temperature rise at cooling water outlet is higher, with the degree decreasing with increase in heat recovery time, as shown in Fig. 3. At a shorter heat recovery time, very little time is available for thermal balance between the adsorption and desorption processes, as compared to longer heat recovery time.

As shown in Fig. 3, when the heat recovery time was 0 seconds, the hot water outlet temperature was smaller than the cooling water outlet temperature for a period of time. This resulted to hot water getting into the cooling tower at a relatively high temperature to release its' heat and a consequent cooling water rushing out of the adsorbing bed through the hot water outlet, into hot water heating system at a lower temperature. For this reason, the heat recovered is smaller than the heat released to the cooling tower, which would result in a lower COP. As the heat recovery time increased, from 0 seconds to 220 seconds, the temperature difference between the hot water outlet temperature and the cooling water outlet temperature difference during the heat recovery time started to increase. This indicated gradual improvement in the heat recycled, that resulting to increase COP, though with gradual decrease in cooling capacity. As seen on Fig. 3, the COP remains higher, but with gradually small increment, as the heat recovery time increased. However, after 160 and 180 seconds for cycle time of 780 and 900 seconds respectively, there was a sharp decrease in COP. The cooling capacity decreased gradually for both cycle times with a sharp decrease when the heat recovery time was beyond 160 seconds.

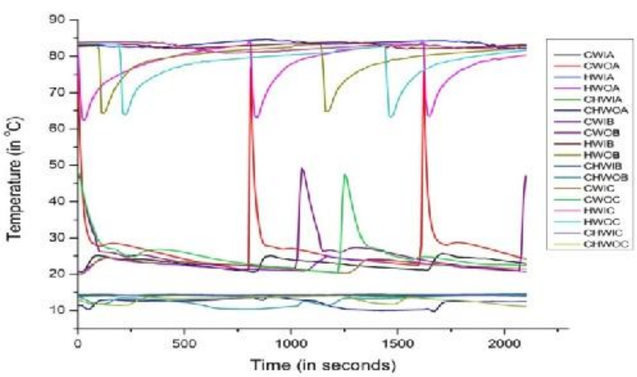

Fig. 3 Temperature profile at different heat recovery times

Average inlet hot, cooling and chilled water temperature was set at 83^{o}C, 24-26^{o}C and 15^{o}C, respectively, with the standard mass flow rates of hot, cooling and chilled water maintained

Note:CWIA = Cooling water inlet with heat recovery time of 0 seconds, CWOA = Cooling water outlet with heat recovery time of 0 seconds, HWIA = Hot water inlet with heat recovery time of 0 seconds, HWOA = Hot water outlet with heat recovery time of 0 seconds, CHWIA = Chilled water inlet with heat recovery time of 0 seconds, CHWOA= Chilled water outlet with heat recovery time of 0 seconds, CWIB = Cooling water inlet with heat recovery time of 120 seconds, CWOB = Cooling water outlet with heat recovery time of 120 seconds, HWIB = Hot water inlet with heat recovery time of 120 seconds, HWOB =Hot water outlet with heat recovery time of 120 seconds, CHWIB = Chilled water inlet with heat recovery time of 120 seconds, CHWOB = Chilled water outlet with heat recovery time of 120 seconds, CWIC = Cooling water inlet with heat recovery time of 220 seconds, CWOC = Cooling water outlet with heat recovery time of 220 seconds, HWIC = Hot water inlet with heat recovery time of 220 seconds, HWOC = Hot water outlet with heat recovery time of 220 seconds, CHWIC = Chilled water inlet with heat recovery time of 220 seconds, and CHWOC = Chilled water outlet with heat recovery time of 220 seconds.

Inlet outlet temperature difference characteristics

Figure 4 shows the temperature difference for the working fluids, with the chillier operating at different heat recovery times. As shown on the figures, different heat recovery duration results to different levels of heat transferred, hence temperature difference in the working fluids inlet outlet conditions. Figures a, b, and c shows hot, cooling, and chilled water temperature difference profiles, respectively, of the chiller operating at a heat recovery time of 40 seconds, figures a, b, and c shows hot, cooling, and chilled water temperature difference respectively of the chiller operating at a heat recovery time of 40 seconds, while Fig. 4 a, b, and c shows hot, cooling, and chilled water temperature difference respectively of the chiller operating at a heat recovery time of 40 seconds.

Heat recovery time has a general effect on the total half cycle time, with shorter or no heat recovery times generally reducing the half cycle time while a longer heat recovery time generally increasing the half cycles times as shown in Fig. 4.

3.2.2.1 Temperature difference between inlet and outlet of hot water

Hot water temperature difference is generally highest at the start of the half cycle due to the high degree of heat transfer between the hot water and the cold bed that was undergoing adsorption process as well as mixing with cooling water in the bed. The temperature difference decreases exponentially as the adsorber bed gains heat till it gets to the temperature almost equal to the temperature of the inlet hot water. During the heat recovery time, the hot water is bypassed and makes the inlet hot water equal to the outlet hot water temperature.

3.2.2.2 Temperature difference between inlet and outlet of cooling water

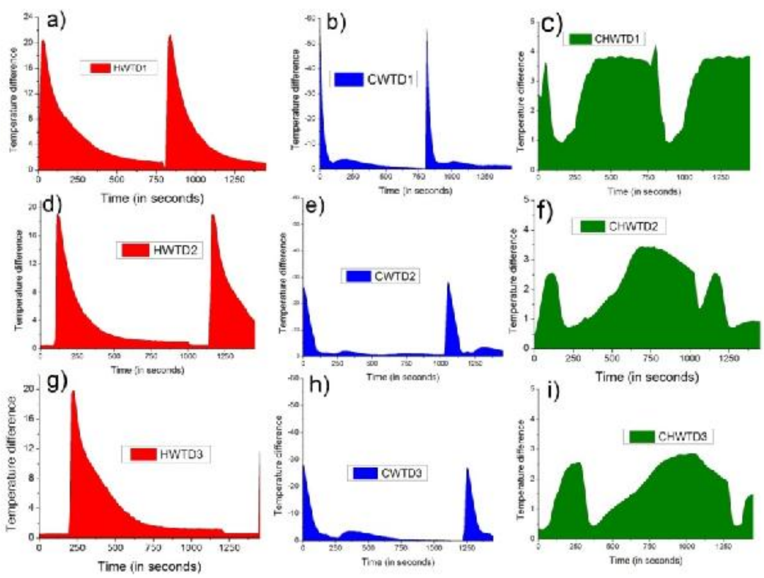

Fig. 4 Temperature difference between inlet and outlet of cooling water

Average inlet hot, cooling and chilled water temperature was set at 83°C, 24-26°C and 15°C, respectively, with the standard mass flow rates of hot, cooling and chilled water maintained

Note:HWTD1= Hot water outlet-inlet temperature difference for heat recovery of 0 seconds, CWTD1= Cooling water outlet-inlet temperature difference for heat recovery of 0 seconds, CHWTD1= Chilled water outlet-inlet temperature difference for heat recovery of 0 seconds, HWTD2 = Hot water outlet-inlet temperature difference for heat recovery of 120 seconds, CWTD2 = Cooling water outlet-inlet temperature difference for heat recovery of 120 seconds, CHWTD2 = Chilled water outlet-inlet temperature difference for heat recovery of 120 seconds, HWTD3 = Hot water outlet-inlet temperature difference for heat recovery of 220 seconds, CWTD3= Cooling water outlet-inlet temperature difference for heat recovery of 220 seconds, and CHWTD3= Chilled water outlet-inlet temperature difference for heat recovery of 220 seconds.

During heat recovery processes, the cooling water temperature difference suddenly increases then drops again from its peak temperature difference value. The abrupt rise in cooling water inlet inlet-outlet temperature difference is mainly contributed by the cooling water flowing into the hot bed previously going through desorption process, in the chamber that just switched from desorption process. The temperature deference drops quickly as the residual hot water is taken from the bed and the bed cooled by cooled water. Cooling water inlet-outlet temperature difference had a generally gradual decrease as time progressed during heating and cooling process. As seen in Fig. 4, cooling water inlet-outlet temperature difference decreases sharply for a short time then slightly increases before finally decreasing. This was mainly contributed by condensation heat gained from the condenser in the chamber undergoing desorption.

Performance characteristics with different heat recovery durations

Figure 5 shows the performance of the chiller operated under different heat recovery time durations. At the beginning of heat recovery process, hot water inlet is bypassed while cooling water is forced into the adsorber bed that is ending the desorption process. Hot water is then forced into the adsorbing bed, which is almost switching to the next desorption process, at the end of the heat recovery process. Generally, at very shorter heat recovery duration, very little time is available for thermal balance between the adsorption and desorption processes resulting to a lower chiller performance. The specific cooling power sharply increases with a slight increase in heat recovery to its maximum, about 265 Watts/kg, and then gradually decreases with increase in heat recovery duration. In a similar way, the COP increases sharply to its maximum, about 0.5, before gradually decreasing as the heat recovery time increases. The best heat recovery was obtained within the heat recovery duration of between 40 seconds and 80 seconds, since they give highest cooling capacity as well as COP values.

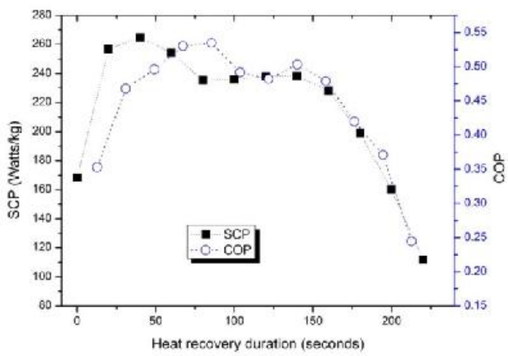

Fig. 5 Variation of cycle COP and SCP with heat recovery duration

Average inlet hot, cooling and chilled water temperature was set at 83°C, 26-29°C and 15°C, respectively, with the standard mass flow rates of hot, cooling and chilled water maintained

Conclusions

In this study, extensive experiments were done on an adsorption chiller filled with composite silica gel impregnated with lithium chloride that employed methanol as an adsorbate. Operation strategies of this two bed adsorption chiller with composite adsorbent, sorbent of Silica Gel impregnated with Lithium Chloride, paired with methanol and driven by a constant heat source were analyzed. Different working conditions on the performance of the chiller were investigated based on experimental results.

Under the standard test conditions of 83°C hot water, 26 °C cooling water, and 15°C chilled water inlet temperatures, a SCP of more than 286 Watts/kg and a COP of more than 0.48 can be achieved. This is a considerable improvement as compared to pure silica gel adsorption chillers. With both best heating source and cooling source temperatures of about 82-87°C and 24-30°C respectively, the composite adsorbent chiller showed a much higher improvement in performance in comparison with pure silica gel adsorbent chillers.The best heating and cooling time is 720s to get the highest cooling power, or it can be set at 780s to get the highest COP. Heat and mass recovery of about 60 seconds provided the highest performance.Considering the best operating conditions in this study, an average COP improvement of more than 27.4% and a SCP improvement of more than 112.6% could be obtained as compared to a similar chiller (studied by Gong(Gong, Wang et al. 2012)) filled with pure silica gel that is paired with water as the adsorbate.

Experimental results showed that the cooling capacity and the coefficient of performance COP can greatly be improved through a set of modest control mechanisms. The results further showed that moderately short heat recovery time provides the best performance results (i.e. cooling capacity and COP) as compared to very long heat recovery time. However, longer heat recovery process coupled with longer cycle time leads to re-adsorption process which is significantly important in saving energy used in heating the hot water. Four main aspects have been considered to outline the significance of optimizing the heat recovery process; cooling capacity, COP, re-adsorption and the driving energy. As compared to other systems, this new system could achieve a COP of as high as 0.65 and a cooling capacity of about 3700Watts, which is a great improvement in the chillers performance.

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Spatial Modelling of Solar energy Potential in Kenya

Francis Oloo[1*], Luke Olang'[2], Josef Strobl[3]

[1]KEMRI-University of Oxford-Wellcome Trust Research Programme, Nairobi Kenya
[2]School of Engineering and Technology, Kenyatta University, Nairobi, Kenya
[3]Interfaculty Department of Geoinformatics, University of Salzburg, Austria

Abstract

Solar energy is one of the readily available renewable energy resources in the developing countries located within the tropical regions. Kenya is one of the countries which receive an average of about 6.5 sunshine hours in a single day throughout the year. However, there is slow adoption and utilization of solar energy resources in the country due to limited information on the spatial variability of the characteristics of solar energy potential. The aim of this study is to assess the potential of photovoltaic solar energy generation in Kenya. The main factors that influence incident solar radiation that we considered in this task included atmospheric transmissivity and the nature of topography. The influence of atmospheric transmissivity was factored in by modelling monthly transmissivity factors from a combination of cloud cover, diffuse ratios and the general effects of altitude. The contribution of topography was analysed by applying hemispherical viewshed analysis to determine the amount of incident global radiation on the surface based on the orientation of the terrain. In order to integrate the different spatial datasets for the study, consistent spatial analysis tools and methods were achieved within a GIS framework. The results obtained showed that on average, about 95% of the land in Kenya has the potential of receiving approximately 5kWh/m^2/day throughout the year. The maps of monthly solar energy potential in the period between April and September indicated relatively large areas of land that can be characterised as high potential areas when compared to the other month of the years. In outline, this comprehensive work successfully assessed the spatial variability in the characteristics of solar energy potential in Kenya and can be used as a basis for policy support in the country.

Keywords: Spatial modelling; solar energy; renewable energy; GIS; Kenya

Introduction

Accessibility to reliable energy sources is critical to the development and well-being of every nation (Acker and Kammen, 1996). According to the Global Status Report on Renewable Energy 2012 (Jaber, 2012:125) , only 51% of Kenyans living in the urban areas have access to electricity while only 4% of those living in the rural areas have access to electricity. Over the years, the primary electric energy supply in Kenya has been through traditional electricity generation sources such as hydro-electric power, thermal oil and geothermal power. The challenges associated with climate change have made reliance on hydro-electric power unpredictable. Additionally, increasing population growth rate continues to complicate energy supply and demand matrix in the country. Despite, these challenges, the geographic position of Kenya within the tropics and precisely on the equatorial region provides an opportunity for the country to tap from the readily available solar energy resources. Kenya is in fact, one of the countries in

Africa where solar energy has been exploited albeit only marginally since 1970s (Ondraczek, 2011:1). The amount of incoming solar radiation incident on the surface of the earth directly from the sun is referred to as direct solar radiation while the amount of solar radiation that hits the earth surface after it has been scattered or reflected by objects within the atmosphere is referred to as diffuse solar radiation. The summation of direct and diffuse solar radiation is known as global solar radiation. The actual amount of solar radiation incident on a unit surface over a period of time is referred to as solar insolation (Kahle et al, 2003: 137).

Even though the amount of solar insolation incident on the earth surface can be measured, the spatial distribution of the measurement instruments and fine temporal resolution of the measured data cannot be obtained for every place and at every instance on the earth's surface (Myers, 2003:1), as a result the use of solar radiation models has been critical for many engineering and economic decisions. While some studies have used the measured meteorological data to estimate solar radiation at unmeasured locations, for instance (Almorox, 2011:54) used measured meteorological data to analyse the relationship between daily global radiation and other meteorological and geographical factors. Other studies have used concepts and data from remote sensing to estimate solar radiation. For instance (Hena et al, 2013:36) used a simple statistical approach to estimate incident solar radiation on the earth's surface from NOAA–AVHRR data. In the study, full resolution NOAA-AVHRR data was analysed and used to estimate ground global solar irradiation. On the other hand, (Hammer et al., 2003:424) used the HELIOSTAT method to derive solar irradiation from satellite imagery.

Furthermore, some studies have used a combination of satellite generated data and direct measurements to map the potential of solar energy. For instance, (Ramachandra, 2007:108) applied GIS concepts on measured meteorological data to map solar energy potential in Kanartaka state in. Similarly, (Ramachandra et al. 2011) used high resolution satellite derived insolation data to map the solar energy hotspots in India. Satellite imagery has also been used for siting and for evaluating the performance of both thermal and photovoltaic solar radiation applications (Azhari et al, 2008). Apart from the varying data sources and models that have been used to study the potential of solar energy in different parts of the world, different methods have also been employed. (Museruka and Mutabazi, 2007) used a non-linear meteorological radiation model for the assessment of global radiation over Rwanda while (Fadare, Irimisose, Oni, & Falana, 2010) modelled the solar energy potential in Africa using artificial neural networks.

Most of the common spatial based models for evaluating the amount in incident solar radiation on the surface of the earth are based on the concepts of hemispherical photogrammetry (Rich et al. 1994). In general the models use the proportion of unobstructed sky and the incident angle of radiation which is obtained from the sun's zenith and angles to compute the amount of incident solar radiation at a particular location. Specifically, the concept is implemented in steps as follows. First, the angular distribution of sky obstruction is specified in hemispherical coordinates system and projected on a plane. Secondly, the sky is divided into discrete number of sectors based on the zenith angle and azimuth angle. The angular area of proportion of unobstructed sky in each sector is then computed. Thirdly, the proportion of each sky sector is multiplied by the irradiance corresponding to the entire sky sectors and also by a factor of cosine weighting for the angle of incidence between the sky sector and the earth surface. Finally, the calculated irradiance for all the sectors are combined to come up with the total incident solar radiation for the point of interest (Rich et al. 1995). Other common terms in solar radiation models include

In spite of the obvious benefits of renewable energy resources, the prohibitive costs of initiating commercially viable photovoltaic solar energy generating plants and lack of accurate information on potential opportunities and markets have been identified as the main hindrances to exploitation of solar energy in Kenya (Theuri, 2008). In this study, we used publicly available geospatial data to assess the potential of solar energy in Kenya. Specifically, we used concepts and methods from Geographic Information Systems (GIS) to combine thematic data from different sources in order to evaluate and to visualize the potential of photovoltaic solar energy in the country.

Methods

Study area

This study was carried out in Kenya. The country lies in the tropical equatorial region with approximately one half of the country in the northern hemisphere and the other half in the southern hemisphere. Spatially, Kenya covers an area of approximately 580,300 km^2 and is located approximately between 5^0S and 5^0 N in latitude and between 32^0E and 42^0 E in longitudes. The full range of elevation in the country is between 0 and 5200 m above mean sea level, the highest point being on Mt. Kenya. According to the 2009 Kenya National Population and Housing Census report, it was reported that the country had a total population of 38,610,097 people

Renewable energy situation in Kenya

Kenya has traditionally relied on hydro-power, thermal oil and geothermal energy as the main sources of electricity for the country. However, in 2004, the government introduced Sessional Paper no. 4 of 2004 in the energy sector whose aim was to help in diversifying sources of energy and to promote the development of renewable energy technology in the country (Ministry of Energy Kenya, 2011). Additionally, the paper looked at ways of promoting rural electrification in order to increase the access to electricity throughout the country. The Energy Act No. 12 of December 2006 established the Energy Regulation Commission (ERC) as the body mandated to offer regulatory stewardship on electricity, petroleum and renewable energy sub-sectors in Kenya. This legislation aimed at promoting the development of renewable energy technologies and international cooperation on programs related to renewable energy. Additionally, the Act was intended to facilitate mainstreaming the utilization of renewable energy resources in electricity generation and in transportation. In order to facilitate resource mobilization for investment in renewable energy generation and to encourage the participation of private sector players in the process, Feed – In Tariffs (FiTs) Policy on wind, biomass, small-hydro, geothermal, biogas and solar resource generated electricity was introduced in 2010 (Ministry of Energy Kenya, 2010).

An assessment of the solar energy market in Kenya indicated that the market is segmented into three tiers. Specifically there are the solar house systems and small-scale commercial applications systems which make up of about three-quarters of the installed capacity, secondly there are systems that provide off-grid electricity to schools, health centres, churches, missions and other social institutions in rural areas and finally there solar powered base stations for mobile communication networks and tourism networks (Ondraczek, 2011). Increased incomes among rural residents especially in coffee and tea rich regions in Kenya has been a motivation for farmers in such areas to acquire solar PV systems (Hankins, Saini, & Karai, 2009). Consequently, the improved solar electrification in rural areas has resulted to increased television use, the expansion of markets and other processes that lead to rural to urban communication like the proliferation of mobile phone technology (Jacobson, 2007). (Acker & Kammen, 1996) also noted that technology transfer where different government institutions and non-governmental organizations have been involved in training the rural residents on the benefits of adopting renewable energy sources as opposed to the traditional sources has also contributed greatly to the accessibility of solar PV systems in rural Kenya. According to the 2009 population census, 4% of households in Kenya were using solar energy as the main source of lighting.

Data processing

Two main themes of data was used in this study, these were topographic data which was mainly derived from digital elevation models and climatic data. A 90m resolution digital elevation model from CGIAR SRTM (Jarvis et al, 2008) was the main source topographic information required in the analysis. Information on elevation is useful for solar radiation potential mapping because it is the main source of topographical characteristics of any area of study specifically providing insight on terrain shading, slope and aspects characteristics. These characteristics are important in sight selection of the high potential areas and for positioning of solar energy generation equipment. The average human settlement line around Mt. Kenya which is the highest mountain in Kenya is located approximately 3000m above mean sea level. The areas with elevation values above 3000m were excluded from the analysis by setting such values to null.

Climate data that was used in this study was sourced from two main repositories. Direct measurements of hourly solar radiation and cloud cover for 23 meteorological stations was downloaded from Solar and Wind Energy Resource Assessment (SWERA) datasets (OpenEI, 2013). The data was available for the 23 stations in varied number of years mainly covering the period from 1973 to 2002. In view of the sparse spatial distribution of the 23 meteorological stations, additional climate data was obtained from NASA Surface Meteorology and Solar (NASA-SSE) radiation data. Specifically, monthly cloud cover data averaged at 3-hour interval was extracted from 300 points covering the entire spatial extent of the study area. The original three-hour (03GMT, O6GMT, 09GMT, 12GMT and 15GMT) cloud cover data tables that were retrieved from the NASA-SSE database was organized by rearranging the data fields so that, after the latitude and longitude columns, the monthly data appeared sequentially from January to December. This arrangement was important for the logical execution of the python script that was used to interpolate monthly cloud cover surfaces. Measured monthly cloud cover values from 23 stations were added to the NASA-SSE cloud cover data tables. The intention of this was to use the measured values as a means of calibrating the monthly cloud cover surfaces.

In order to come up with continuous average monthly surfaces of cloud cover data, Inverse Distance Weighting (IDW) method of spatial interpolation was implemented on the data. IDW method which is a local and exact interpolation method was chosen in order to ensure that interpolated values were close as possible to the observed values and to restrict the interpolated values to the range of the observed data values. The interpolation process was automated using a python script within ArcGIS 10.2 software. From the Typical Meteorological Year (TMY) data from the 23 stations in Kenya, the data fields which were extracted for this study included extra-terrestrial horizontal radiation, global horizontal radiation, direct normal radiation, diffuse horizontal radiation and total sky cover. Additional, date columns which included year, month and day were also used to bring in the spatio-temporal characteristic of the data.

Modelling solar radiation potential

In summary, the model implemented in this study involved two main parts. The first aspect involved using interpolated monthly cloud cover layers estimate monthly transmissivity factors for the area of study. Transmissivity factor or the transmittance of the atmosphere refers to the proportion of the incident radiation at the top of the atmosphere that successfully penetrates through the atmosphere to hit the ground surface. Atmospheric transmission factor can be computed as the ratio of the global solar radiation incident on a horizontal surface to the extra-terrestrial horizontal radiation (Hena et al., 2013). (Pons & Ninyerola, 2008). Additionally, since physiographic characteristics of terrain including elevation, slope, aspect and topographic convergence have also been found to have in an influence on meteorological elements including solar insolation (Dobrowski, 2011), an elevation factor equivalent to the product of 2.2×10^{-5} (Bintanja, 1996) and elevation at a particular station should be added to the transmission factor to increase transmittance with altitude (Pellicciotti, Raschle, Huerlimann, Carenzo, & Burlando, 2011). In this study a simplified formula introduced by (Hena et al., 2013) was used. In the formula, the relationship between transmissivity factors for an overcast sky k_b, transmission factor for a clear sky k_c and the cloud cover index n^t can be used to estimate a representative transmission factor k^t at a particular location.

$$k^t = n^t k_b + \quad 1 - n^t \quad k_c$$

In this study, we calculated representative transmission factors for clear sky k_b and the transmission for an overcast sky k_c as ratios of daily incident global radiation and daily extra-terrestrial radiation from each of the 23 stations. An average of the calculated maximum transmissivity factor from the 23 stations was assigned to k_b, specifically, the value was 0.83. On the other hand the transmissivity factor for an overcast sky was set at 0.12. This value was obtained from the average of the minimum transmissivity factors calculated at the 23 TMY stations. Monthly cloud cover surfaces were used to represent the cloud cover index n^t.

The second aspect of the solar energy model involved modelling representative monthly global radiation layers from the digital elevation model. Solar Radiation Analyst tool which is one of the tools within the Spatial Analysis toolset in ArcGIS 10.2 was used to create global solar radiation surfaces from the digital elevation. The Solar Radiation tool uses the relationship between elevation and the visible sky size, the transmission factor, diffusion ratio and the sky obstruction caused by features in the vicinity of the location of interest to compute the amount of solar insolation incident on that particular location (Huang, Rich, Crabtree, Potter, & Fu, 2008). Specifically, (Paul M. Rich et al., 1995) identified that topography has two important influences on the amount of insolation at a particular location. First and foremost, the orientation of the surface determines the angle of incidence of solar radiation on the surface. Secondly, the features in the vicinity of the location of interest determine the amount of insolation that can be incident on that location. Apart from the elevation model, the other inputs in the Solar Radiation tool include theoretical and empirical values of transmissivity factor and diffuse ratio among others (Huang et al., 2008)(Rich et al. 1994). Monthly diffuse ratios were computed from the station data. The Solar Analyst tool was configured to estimate monthly radiation for every 10 days within a month, for each day considered in the analysis; the model generates a radiation surface for every quarter of an hour. The overall global radiation surface for that specific day is computed as a summation of the quarter-hour surfaces. The 10-day global radiation surfaces were then used to compute monthly average radiation surfaces. The final step in the analysis involved multiplying the estimated monthly global radiation surfaces by monthly transmissivity factors to obtain representative potential monthly solar energy surfaces for the area of study.

Results

We obtained three main sets of results from the methodology that was implemented in this study, these included, interpolated monthly cloud cover surfaces, monthly transmissivity factor surfaces and monthly potential solar radiation surfaces. In this paper, we only present and analyze the results of monthly solar radiation surfaces. Figure 1 shows the maps of estimated average daily solar energy potential for each month in Kenya.

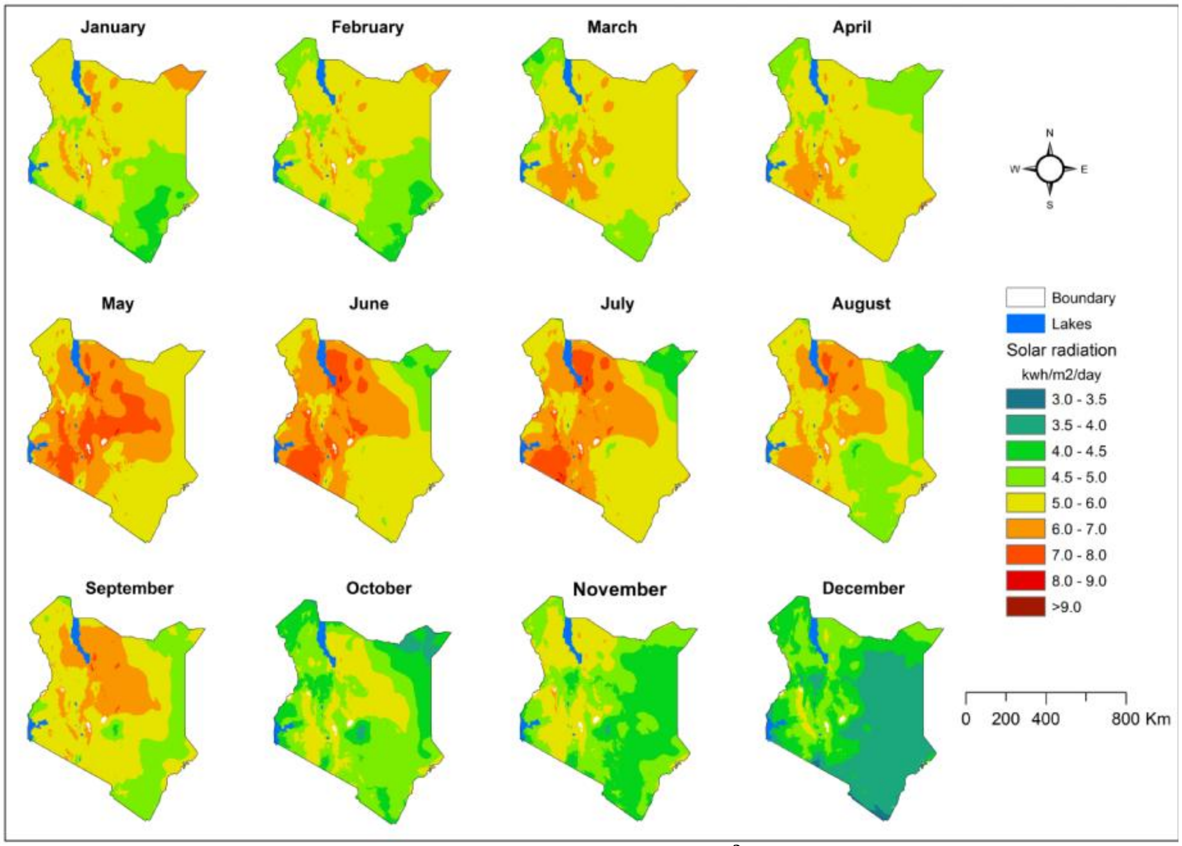

Figure 1: Estimated average daily solar energy potential (in kwh/m^2/day) for each month in Kenya

From the maps of estimated monthly solar radiation, we observed that the months between March and September are generally characterised high values of solar radiation with large area of land in receiving radiation above 5kWh/m^2/day. We particularly noted that in the month of May, the minimum value of estimated incident radiation was approximately 4.9 kWh/m^2/day (and an average radiation of 6.2kWh/m^2/day). On the flipside however, the months of October, November and December recorded lower values of solar radiation with average estimated solar radiation of 4.72kWh/m^2/day, 4.76kWh/m^2/day and 4.14kWh/m^2/day respectively. In the months between January and March, the average estimate solar radiation in the area of study was 5.4kWh/m^2/day.

Figure 3 shows the box plot of estimated average daily radiation for each month in Kenya. The box indicates the IQR (25% and 75%); the line within the box represents the median and the bars represent the range of solar radiation potential in each month. The values are calculated from the pixel values of the estimated monthly solar radiation surfaces. The spatial resolution of each pixel was 100 by 100m. From the results, we observed that between March and September, the average solar energy potential in Kenya is generally above 5.5kWh/m^2/day.

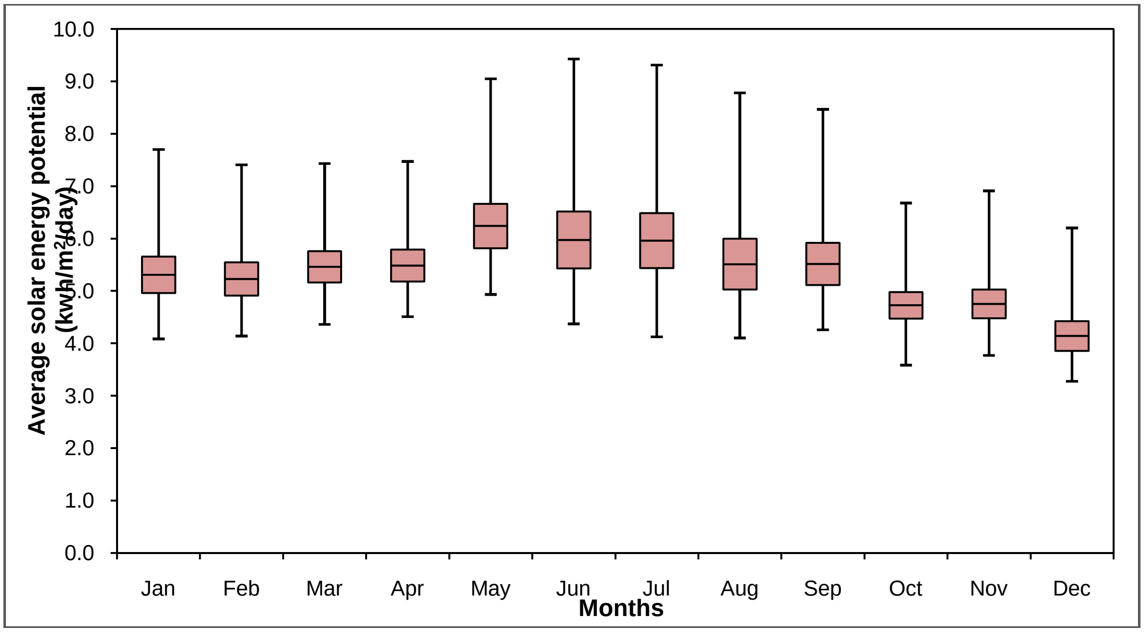

Figure 2: Estimated daily average solar energy potential for by month in Kenya

From the monthly solar radiation surfaces, we calculated an average annual solar radiation potential results of which are shown in figure 3. From the maps, we observed that the highest values of annual solar radiation potential were observed in the regions neighbouring the rift valley and also in the regions around Mt. Kenya. Similarly, high values of solar radiation potential were also recorded in the western region of Kenya, particular those that are near Mt. Elgon. Relatively lower potential areas were predicted in the costal planes and in the eastern regions of Kenya (mainly in the former North Eastern Province of Kenya).

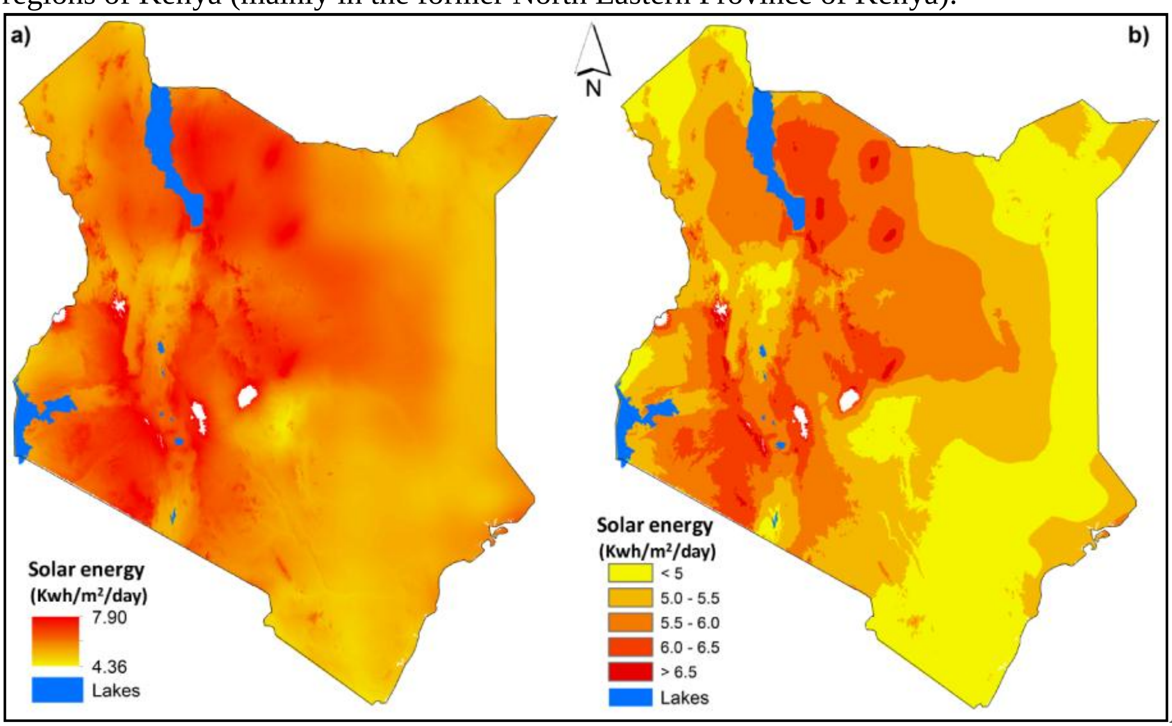

Figure 3: Spatial variation of solar energy potential in Kenya at 100 x 100m spatial resolution. a) Continuous average solar energy potential in kwh/m^2/day b) Classified average solar energy potential in kwh/m^2/day

Using the solar energy potential classes indicated in Figure 3b, we calculated the areas of land covered by the respective classes in Kenya. Figure 4 represents the areas of land in Kenya characterised by different classes of solar energy potential.

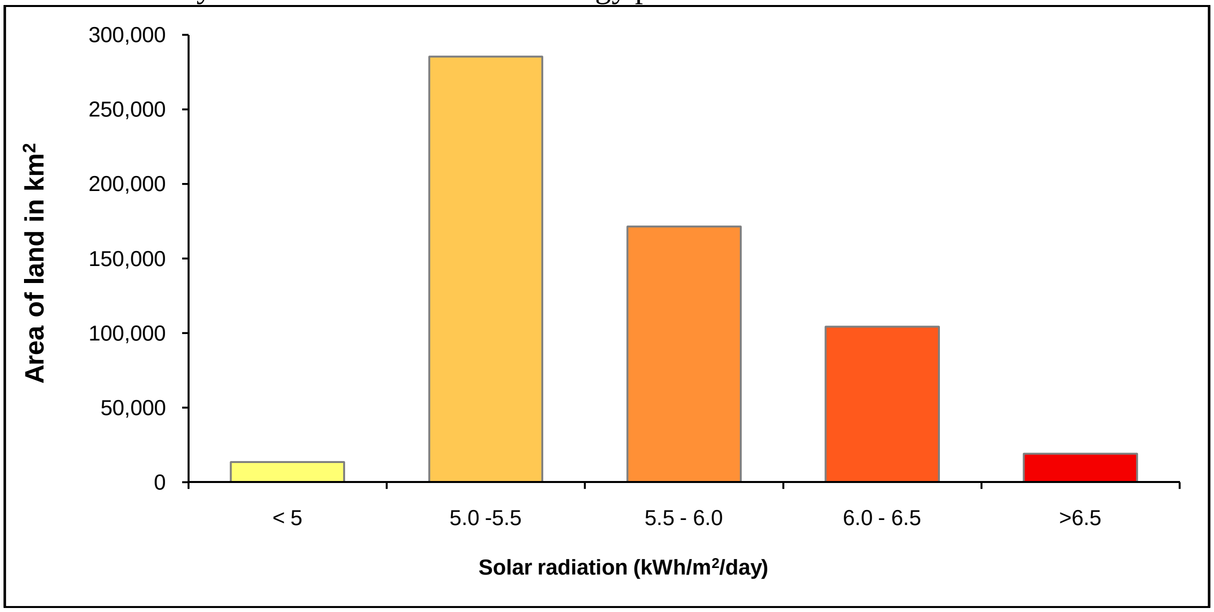

Figure 4: Areas of land characterized by different solar energy potential classes in Kenya.

In summary, we noted that an area of approximately 285,400km^2 (48%) of the total land the in Kenya was predicted to receive between 5.0-5.5kWh/m^2/day of solar energy. Secondly, 171,420km^2 (29%) of the land area was estimated to a potential of receiving between 5.5-6.0kWh/m^2/. The third significant category was that which was estimated to receive between 6.0-6.5kWh/m^2/day of solar radiation, this occupied approximately 104,380km^2 (17.6%) of the land total land area. In the highest solar energy potential class, approximately 19,100km^2 (3%) of the land area was characterised to receive more than 6.5kWh/m^2/day of solar radiation and only approximately (13,600km^2) 2.3% of the land area was estimated to receive less than 5kWh/m^2/day of solar radiation.

Model validation

Measured monthly average solar radiation data from 7 TMY weather stations were compared with the model values which were extracted from the monthly solar radiation surfaces. The choice of the 7 stations was based on the availability of long term measured climatic data and their spatial spread across the country. The stations whose data was used for validation were Dagoreti, Garissa, Lodwar, Kisumu, Marsabit, Mombasa and Nyeri. A total of monthly 84 data points (12 months in the seven stations) were used in the validation.

The mean error in the estimation of solar energy potential revealed low overall bias with a tendency to under-estimate radiation values by -0.29kwh/m^2/day. The root mean square error was at 0.49. The correlation between the measured and estimated values of solar radiation was 0.6 indicating a strong linear agreement as shown in Figure 5. The dotted line represents the line of best fit between the measured and the estimated values of solar radiation.

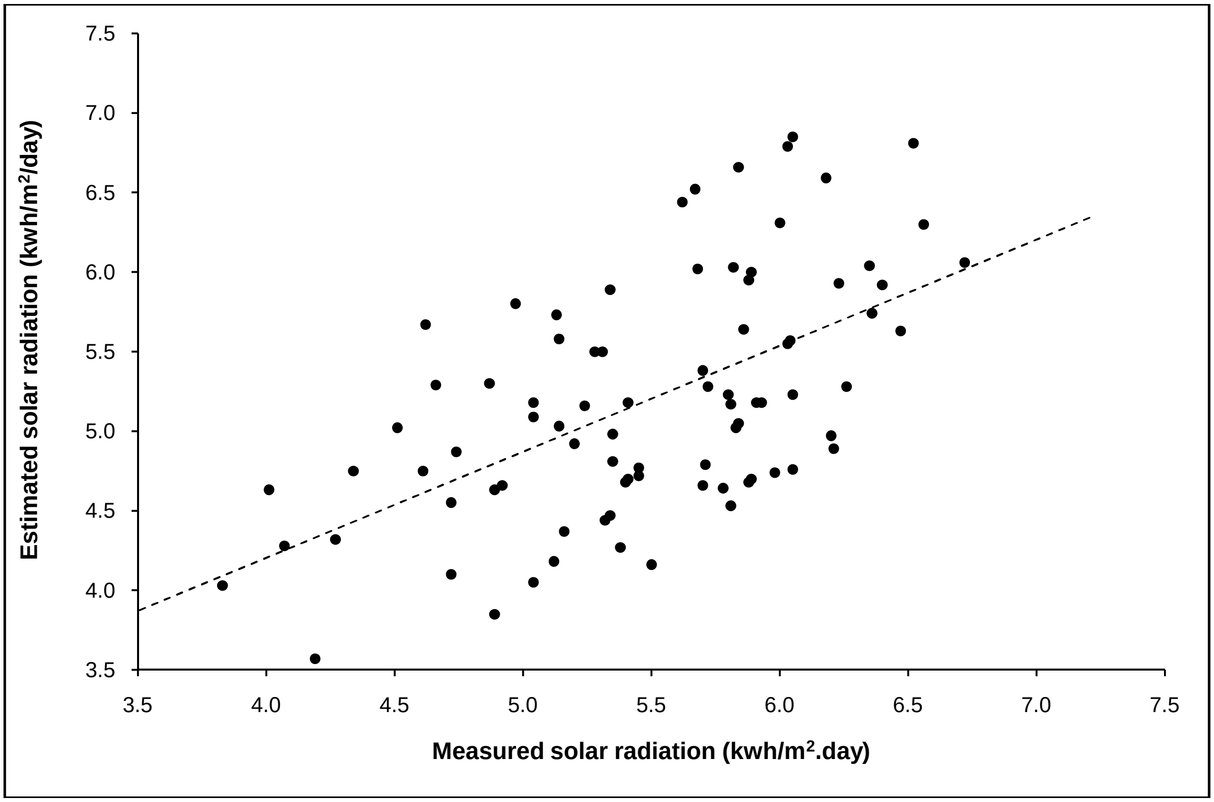

Figure 5: Scatter plot of measured versus estimated solar radiation for the validation set (n=84)

Discussion

In this work, we successfully processed publicly available meteorological data and combined the same with estimated global radiation surfaces which were modelled within a GIS environment. The result was raster surface and statistics on the monthly and annual solar energy potential in Kenya. The plausibility of the main results from the study was confirmed by comparing the model results with measured data in cases where measured data was available.

From the study, we estimated that approximately 95% of the land area of Kenya has an annual solar energy potential above 5kWh/m^2/day. Specifically 48% of the land has an average annual solar potential ranging between 5.0-5.5 kWh/m^2/day, additionally, approximately 29% of the country's land area has the average annual solar energy potential in the range of 5.5-6.0 kWh/m^2/day. Further still, above 20% of the land area in Kenya has the potential of receiving more than 6kWh/m2/day of solar energy. The very high potential areas, that is, the areas which were estimated to receive solar radiation above 6kWh/m^2/day were mainly located in the high altitude ridges of rift valley and also in the regions to the east of Lake Turkana and specifically around Marsabit. The spatial distribution of high potential areas in the country shows that investments in solar energy generation in the high potential areas can not only ensure adequate load for solar equipment but also increase the accessibility to electricity and other benefits of solar energy resources to more residents of the country especially those who inhabit far flung rural areas with little or no access to electricity at the moment.

In this study, we have been able to show that it possible to use publicly available data to accurately model solar irradiation at very high resolution, specifically we were able to model monthly solar radiation surfaces at 100 by 100m in Kenya. We however note that integration of accurately measured meteorological data especially in mountainous areas into the solar energy

models can greatly improve the accuracy of results. Specifically, integration of different kinds of meteorological data with an influence on solar irradiation processes can greatly improve the respective solar radiation models.
One of the challenges that we experienced in the course of this study was the general lack of up-to-date and long-term archives of measured meteorological data in the Kenya. We therefore recommended that in view, of the benefits that are likely to be accrued from the exploration and exploitation of renewable energy resources in Kenya specifically and in Africa in general, there is need to improve the network of meteorological stations and to make available the datasets from these stations to allow for research in natural resources and specifically renewable energy resources. The model that we implemented in this study mainly relied on the topographic characteristics of the area of study and on atmospheric transmissivity which we mainly estimated from cloud cover surfaces. We therefore recommended that broader models which allow for more covariates including precipitation, relative humidity and atmospheric aerosol content should be examined as a way of refining the results further. Additionally, accurately measured and up-to-date meteorological data should also be integrated into such models. Finally, while the result from this study have been impressive, additional analysis on the economic viability of solar energy generation in the high potential areas should be carried out before any commercial projects are rolled out.

AUTHORS
First Author: Francis Oloo, Research Officer. Department of Public Health Research, Centre for Geographic Medicine, KEMRI-University of Oxford-Wellcome Trust Research Programme, P.O. Box 43640-00100, Nairobi, Kenya. +email. oloofrank@gmail.com
Second Author: Dr. Luke Olang', Lecturer, School of Engineering and Technology, Kenyatta University. P.O BOX 43844-00100, Nairobi, Kenya

Third Author: Prof. Josef Strobl, Interfaculty Department of Geoinformatics, University of Salzburg, Hellbrunner Strasse 34, 5020 Salzburg, Austria, +email josef.strobl@sbg.ac.at

Corresponding Author: Francis Oloo, P.O Box 28893-00200, Nairobi. Tel +254722173755. Email oloofrank@gmail.com

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Use of Gas-Diesel as Alternative Fuel for Internal Combustion Engines

Alfayo Ongeri*, George Magore, Jeremiah Kiplagat
Kenyatta University, P.O. Box 43844 – 00100, Nairobi – Kenya
*Email: brialf49@yahoo.com

Abstract: With the expected tripling of the global light duty vehicle fleet and a doubling of its CO_2 emissions, the importance of addressing fuel efficiency in road transport is rising on global and national environment, energy, and climate change issues. This paper examines the way of reducing harmful effects of exhaust gases of diesel engines on the environment and reviews the research carried out by various scientists in different diesel engines. Gas-diesel fuel mixture under high pressure is introduced to the combustion engine. These engines, which use conventional diesel and gaseous fuels, are referred to as 'dual-fuel engines'. This improves the engine performance, consequently, reducing the content of nitrogen oxide in the exhaust gases thus causing harmful effects on the environment.

Key words: gas-diesel fuel, natural gas, nitrogen oxide, toxic emissions

Introduction

Modern automotive technologies use petroleum products (petrol and diesel) as fuel. Reduction of oil reserves, increasing prices, energy crises, catastrophic environmental pollution by exhaust gases, the growing dependence of many countries on imported hydrocarbon fuel, the threat of global warming are the main circumstances that necessitate the search for alternative fuels (IEA, 2008 and WBCSD, 2004b). Road transport is responsible for 17-18% of global CO_2 emissions from fossil fuel combustion, and in most countries transport CO_2 emissions are growing at a faster rate than total CO_2 emissions (OECD/ITF, 2008a).

A global shift to a greener, low carbon economy will require significant improvement in the ways in which energy is produced and used. The transport sector uses over a quarter of the world's energy and is responsible for a comparable share of global CO_2 emissions from fossil fuel combustion. This will require both systemic and more specific technological solutions, such as: smart growth urban planning for fewer motorized trips, increased mode of share for non-motorized and public transport, shifting incentives to more efficient and less polluting modes and technologies. This takes advantage of best available and most fuel and energy efficient technologies (UNEP, 2009).

The global light duty vehicle fleet is expected to triple by 2050. Most of this growth will take place in transitional and developing countries like Kenya (50by50 campaign). Therefore, special attention needs to be paid to controlling the fleet sizes and composition on a global level in the medium and long term situation. When exploring solutions to lower road transport emissions and improve fuel efficiency, policy makers, industry, and consumers often look to technology that has proven to be cost effective. Gas-diesel fuels, along with other cleaner vehicle technologies, are increasingly on the list of options (UNEP, 2009).

With increasing restrictions of tailpipe emissions from vehicles powered by internal combustion engines (ICE) and growing concern over the use of liquid hydrocarbon fuels, alternative fuels have gained popularity. Natural gas (NG) is a promising alternative fuel to diesel fuel for road transport vehicles. The use of NG as a fuel has been growing in recent years due to the considerable economic and environmental advantages. Its low cetane and high octane numbers are extraordinarily suitable for spark ignition (SI) engines and it can be used in high compression ratio ignition (Genesan, 1999).

Literature review

Research work world-wide involving the use of natural gas in internal combustion (IC) engines has been intensified due to environmental concern and/or exhaustion of conventional fossil fuels (Karim & Ali,1975).The renewable energy sources, natural gas, bio-derived gases and liquids appear to be greener alternative sources for ICE (Nwafor, 2000: 495–504 & Nwafor, 2000: 11-20). The fuel system of a natural gas engine is somehow different from that of the liquid fuel engine. Means for utilization of natural gas in SI engines are well established and documented whilst development efforts are still going on towards its use in compression ignition (CI) engines due to various problems. Natural gas has longer ignition delay and slower burning rates compared to diesel fuel operation (Nwafor & Rice, 1994: 841). Again it has high self-ignition temperature (SIT) of about 704^0C, (Stephenson & Raine, 1980: 48). It therefore, cannot be used in CI engines without a means of initiating combustion since the temperature attained at the end of compression stroke is relatively lower than the SIT of the gas. In the gas-fumigated dual-fuel engine, the primary fuel is mixed with air outside the cylinder before it is inducted into the cylinder. A mixture of gas and air is compressed during the compression stroke and before the end of the stroke; a pilot quantity of diesel fuel (depending on the operating conditions) is injected to initiate combustion. The combustion processes of dual-fuel engines lie between that of the CI and SI engines. The longer burning rate of the gas allows more time for heat transfer to the end gas resulting in a tendency to knock (Moore & Mitchell, 1955: 330).

Dual-fuel gaseous engines operate under different design parameters which include load, speed, compression ratio, fuel injection timing, fuel mass, inlet manifold condition and composition of dual fuel. These parameters cause variations in engine performance. Numerous studies have been carried out by many researchers to examine the effect of different design parameters on the emissions, performance and combustion characteristics of gas-diesel engines. These investigations by the researchers are conducted in different test engines with various gaseous primary fuels and pilot fuels. The results on type of test engine and fuels for dual fuel operation used by various researcher(s) are given in Table 1 below.

Research carried out (Likhanov & Saikin, 1994: 224) on developing methods to combat harmful effects of exhaust show that natural gas is clean fuel, colorless and odorless. Its density is two times lower than that of air, it is environmentally friendly and does not depend on oil reserves. The environmental impact of burning gas fuels in internal combustion engines (ICE) results in the reduction of lead oxide and CO_2 emissions (Likhanov, 2002: 280 & Kuznetsov, 2004: 195).

Diesel engines can be converted to run on gas either by conversion to SI, or by dual fuelling (gas-diesel). The latter retains diesel injection either at a minimum level or at a higher level if necessary to overcome combustion problems. There is some debate over which method is the preferred option. The second option looks the best due to its ability to rapid reversion to full diesel mode when a gas supply is depleted. Dual fuelling has a strong capital cost advantage but this may not be so with gas operated engines that are purchased directly from the manufacturer in the form required (Mbarawa & Milton, 2005).

Table 1.

Summary of experimental investigation by various researcher(s) on dual-fuel usage.

Researcher(s)	**Test engine**	**Pilot fuel**	**Primary fuel**
(Abd, et al. 2002: 269; 2000: 559)	Single cylinder, four stroke, water cooled engine (Ricardo E6)	Diesel	Methane, propane
(Badr, et al. 1999: 1071)	Two single cylinder, 4-stroke, water cooled, DI, normally aspirated laboratory dual-fuel engines	Diesel	Methane
(Bari, 1996: 1007)	Two cylinder four stroke cycle diesel engine (16.8 kW at 1500 rpm, Model-2105 Nang Chang Company, China), water cooled, naturally aspirated with double swirl combustion chamber	Diesel	Biogas
(Henham & Makkar, 1998: 16)	Two-cylinder, four-stroke, water-cooled, IDI Lister Petter LPWS2 diesel engine	Gasoline	Biogas
(Krishnan, et al. 2004: 665)	Single-cylinder DI, CI engine	Diesel	NG
(Kusaka, et. al. 2000: 489)	Water cooled, 4-stroke-cycle, and 4-cylinder conventional DI diesel engine	Diesel	NG
(Mansour, et al., 2001: 409)	Naturally aspirated, V-8 Deutz FL8 413F four cycle diesel engine	Diesel	NG
(Nwafor, 2000: 11-20; 2003: 22; 2002: 375)	Petter model AC1 single cylinder, air-cooled, high speed, IDI, four-stroke diesel engine	Diesel	NG
(Nwafor & Rice, 1994: 841)	Petter model AC1 single cylinder, air-cooled, high speed, IDI, four-stroke diesel engine	Diesel	NG
(Papagiannakis & Hountalas, 2003: 253)	Single cylinder, naturally aspirated, four stroke, air cooled, DI, high speed, Lister LV1 diesel engine with a bowl in piston combustion chamber	Diesel	NG
(Papagiannakis & Hountalas, 2004: 2971)	Single cylinder, naturally aspirated, four stroke, air cooled, direct injection, high speed, Lister LV1 DI diesel engine with a bowl in piston combustion chamber	Diesel	NG
(Selim, 2001: 473)	Ricardo E6 single cylinder variable compression IDI diesel engine	Diesel	Compressed NG
(Selim, 2004: 411)	Ricardo E6 single cylinder variable compression IDI diesel engine	Diesel	CH_4, CNG, LPG
(Singh, et al. 2007: 1565)	A naturally aspirated multi cylinder DG with matching alternator	FD	Producer gas
(Uma, et al. 2004: 195-203)	Direct injected six cylinder, vertical, four stroke engine with mechanical injector	Diesel	Producer gas

Mode of operation

Dual fuelling is a method of utilizing gaseous fuels, whereby the primary fuel (gaseous fuel) is premixed with fresh air in the intake manifold (injected into the cylinder) and inducted into the cylinder and ignited by a small quantity of diesel fuel as the piston approaches the end of the compression stroke. During this stroke, the premixed gaseous fuel-air charge becomes subjected increasingly with time to higher temperatures and pressures as top dead centre is approached. Towards the end of the stroke, a small quantity of diesel fuel is injected into the cylinder under high pressure from 10 MPa to 150 MPa depending on the type of diesel fuel injection system. The finely atomized fuel particles mix with air to form a combustible mixture which, following some physical and chemical changes self-ignites due to high temperatures of the compressed gaseous fuel-air mixture. The flame subsequently consumes the gas within the spray in a direct manner or establishes a progressive flame that moves away from the ignition source. In order for the ignition to be successful, the energy release rate in the early stage of the ignition must be greater than losses from the ignition flame kernel. If not, the flame extinguishes prematurely.

There are two efficient ways of using diesel engines with natural gas as quality fuel: convert a diesel engine to an engine with spark ignition and change the diesel engine to natural gas. The first requires careful engineering on the base engine modification as well as the control system: the fuel equipment which is the injector ignition is replaced with a spark plug ignition system. The second way is based on an appropriately shaped combustion chamber which allows proper air-fuel mixing and directly injected gas into the cylinder (Likhanov, 2002: 280).

Pre-mixed air flows into the cylinder, it is compressed by the piston and at the end of the compression stroke, the injector through its nozzle injects a small amount (glow dose) of diesel fuel, which is ignited and sets fire to the whole mass of gas-air mixture.

Dual fuelling system is divided into gas and diesel systems. The gas system has the following elements:

cylinders for compressed gas;

distribution pad designed to open the pipelines from the front and back of cylinders with the help of an extension and inlet valve;

compressed gas heater, water jacket which is connected to the engine cooling system;

high pressure gas gear (reducer), single stage diaphragm type;

safety valve gear.

When working in this mode 70 – 85% fuel is natural gas. (Likhanov, 2002: 280 and Stadnik, 2002; 18). This option does not require structural or technological change of the basic model of the diesel engine; however it’s possible to switch from dual fuelling to normal diesel cycle.

4.0. Benefits of gas-diesel technology

Gas-diesel engine technology takes advantage of the inherent efficiencies of the compression stroke engine and dramatically reduces the consumption of diesel fuel, resulting in an engine that is more powerful and efficient than a dedicated spark-ignited natural gas engine and substantially reduces emissions. Gas-diesel engines offer the best of both worlds with attractive maintenance costs and demonstrable return on investment. The following are some of the substantial benefits:

4.1. Cost Savings

Lower operating cost than a diesel engine,

Better fuel economy than a dedicated natural gas engine,

Favourable payback periods,

Can be converted back to dedicated diesel, protecting its resale value.

4.2. Power and Efficiency

Power and efficiency equivalent to a diesel engine,

Operates at the same compression ratio as the diesel engine, un-throttled with lean-burn combustion.

4.3. Low Emissions

Emissions equivalent to a dedicated natural gas engine, with lower carbon dioxide emission (CO_2),

Compared to the diesel engine, the gas-diesel engine delivers lower emissions of the following:

Oxides of nitrogen (NOx), Particulate matter (PM), Soot (smoke), Carbon monoxide, Non-methyl hydrocarbons and Carbon dioxide (and total greenhouse gases).

Fuel Flexibility

Gas-diesel engines can operate on 100% diesel if gas is not available,

Gas-diesel engines can operate on either liquid natural gas (LNG) or compressed natural gas (CNG) storage systems.

5.0. Conclusion

A research on toxicity levels of exhaust gases of an internal combustion engine to clean diesel fuel and gas-diesel mixtures (Table 2) shows that levels of harmful nitrogen oxide emissions drops by 30%, soot by 60%, solid particles by70%. In the exhaust, there are increased hydrocarbons (CH), which are not carcinogens produced by the engine, but the unburned harmless methane. In addition, the use of gas-diesel engine provides noise reduction, formation of homogeneous mixture, high energy hot mixture, lack of detonation in the combustion chamber of the engine with high compression ratio, high and complete burn of fuel in combustion and low capacity of soot in the exhaust gases. Diesel fuel savings when using this method is 70 – 80%. The comparative results of toxicity with the conventional engine are shown in the following table.

Table 2

Operation toxicity of diesel engine and gas-diesel engine (Gureev, 1993: 332).

Parameters	Diesel mode	Natural gas mode
Quantity of diesel fuel, %	100	10-15
Specific fuel consumption, g/kWh	295	301
NO_X, g/kWh	6.55	4.10
CO_X, g/kWh	4.54	6.99
Solid particles, g/kWh	0.46	0.16
Soot, g/kWh	0.42	0.12
Hydrocarbons, g/kWh	0.70	0.82

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The Role of Renewable Energy in providing Energy in Rural Kenya

George K. Ngusale[1], YonghaoLuo[1,*1], Isaac K. Kiunga [2],Cao Yang[1]
[1]Institute of Thermal Engineering, Shanghai Jiaotong University, 200240 Shanghai, China
[2]School of Engineering & Technology, Kenyatta University, P.O Box 43844-00100, Nairobi, Kenya

Abstract
Renewable energy supply in sub-Saharan Africa has been necessitated by unmet demand for energy in the need for diversification of energy supplies, as well as by the increasing deleterious environmental impact of fossil fuels use and theirlimited reserves.
In Kenya, hydropower is the main source of energy. At peak, hydropower supplies over 40% of the country's electricity. Recently, the frequent unstable electricity supply from the various hydropower plants caused by frequent prolonged drought seasons and/or climate change has raised concern. This is because, the water reservoirs/damsare reduced substantially below threshold required for hydropower generation. To remedy these, the Kenyan government does put the thermal generation sources on standby mode. Meaning, in the event of low hydro capacity,the thermal sources are immediately put on the grid. This is costly and discouraging to the end use consumer. However, hydropower sources are site-specific (designed to tap into existing natural flow of water in a given area). This ensures the economical and practical viability of utilizing the hydropower within a particular area. Consequently, this might hinder the centralized and grid connected electricity in a widespread or sparsely populated rural area. Globally, there is the need to use energy to reduce 'rural poverty'. This paper explores how renewable energy systems/applications based on local or decentralized grid can be rapidly commercialized to overcome energy 'deficiency' in the rural areas. The renewable energy systems could be made available to the 'rural poor' at an affordable price.

Key words: renewable energy, Kenya, poverty, policy, rural

Introduction

The Kenya's National Energy Policy facilitates provision of clean, sustainable, affordable, reliable and secure energy services at least cost while protecting the environment(Ministry of energy & Petroleum, 2014). This is done using three policy tools that promote the uptake of renewable sources as summarized in Fig.1. The main aim of the policy is to close the energy demand gap, increase energy supply thus ensuring the economic well-being of the rising population.

[1 *]Corresponding author. Tel.: +86 21 34206047; fax: +86 21 34206115
E-mail address: yhluo@sjtu.edu.cn (Y.Luo)

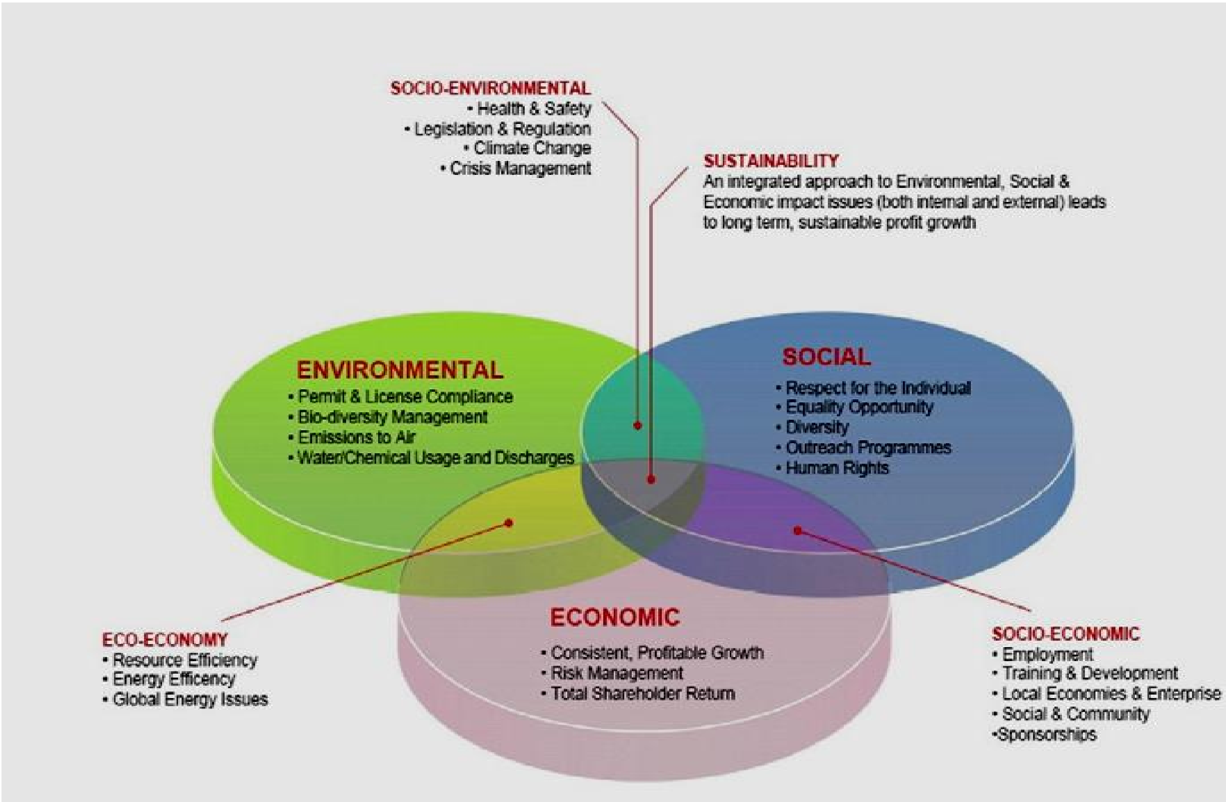

Fig.1. Summary of the three policy tools: environmental, economic & social (Courtesy of SHS World History, webpage)

At present, less than 30% of the entire population of which about 5% are in the rural Kenya has access to electricity (World Bank, 2009; Ministry of energy & Petroleum, 2014) as shown in Fig.2. Renewable energy (RE), derived from sources such as hydro, solar, geothermal, wind, and biomass, has potential to ensure energy reliability, security, generate income and reduce greenhouse gas emissions. Despite the potential, there still exist constraints to optimal RE utilization especially in the rural areas. According to a study (Twidelland Weir, 2006), households in rural areas are characterized by unmet or inefficient basic needs such as lighting with kerosene and/or cooking with firewood. The demand for electricity from rural households is often too small to justify the cost of grid electrification. The most common services derived from electricity include: providing lights especially at night (while eating or enable children/students study); watch television; listen to radio, to mention just but a few. These services can almost certainly be met from renewable energy sources. This calls for RE sector reforms with the hope that the rural population will be able to access energy through market mechanism. It is noted that a vast majority of the rural population have no role in the market mechanism as a result of inadequate purchasing capacity. The access to commercial sources of energy, at whatever price, is not only ‘a dream’ but also ‘a nightmare’. Therefore, energy supply to the rural poor needs to be planned in a financially acceptable form to the benefit of the rural poor.

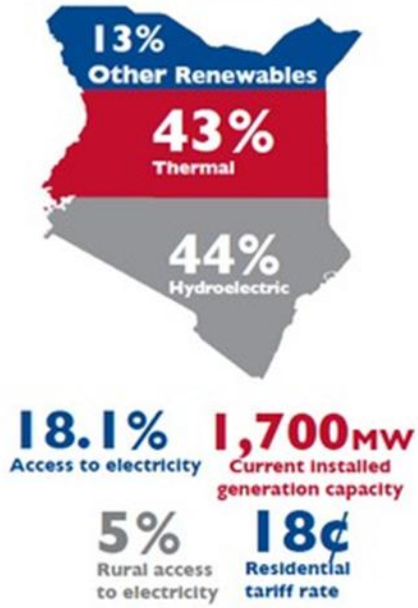

Fig.2. Current generation input mix (Courtesy of Solar Choice 2014, webpage)

Status of rural energy programmes

In a joint publication (Karekenzi, 2002; Sustainable Development Department, 2014), energy is essential for the fulfilment of basic needs and for sustainable rural development, including energy for agriculture, food processing and education. The publication further raises awareness of the impact energy poverty has on hunger, health and other aspects of rural development. However, for rural energy poverty to be reduced three imperatives are emphasized by some leading Agencies (WEC, 1999; FAO, 2000).

Policy makers need to give rural energy development a higher priority for rural dwellers are majorly characterized by 'energy poverty'. According to (Reddy, 2000), 'energy poverty' is the absence of sufficient choice in accessing adequate, affordable, reliable, high quality, safe and environmentally benign, energy services to support economic and human development. The rural dwellers often restrict purchases for energy carriers to those of using kerosene or candles and at times obtain small batteries for torches and radios (Smith, 1999; Reddy, 2000). Quite a few use the rechargeable car batteries for entertainment and/or television systems.

Rural energy development must be decentralized to place rural people themselves at the heart of planning and implementation. Decentralization would ensure that the rural dwellers who often live in the more remote areas characterized by small, scattered settlements access energy carriers. Also, this would help reduce the cost of distribution systems and the overlay capital of the grids (Amulya et al, Date unknown).

Rural energy development must be integrated with other measures dealing with agriculture, education, infrastructure, social and political factors.This would help 'bundle' the provision of rural energy with other essential services.A study in Peru (Barnett, 2000) found out that the addition of a fourth service for rural dwellers has had an effect seven times greater than the addition of the second service.

The government established the Rural Electrification Authority (REA) under section 66 of the energy Act, No.12 of 2006to accelerate the pace of rural electrification in the country(Ministry of energy & Petroleum, 2014). As much as the role REA executes is desirable, the course is not easy and at times very challenging. Firstly, REA's objectives and priorities should be defined and designed by the rural poor and not by outsiders so as to capture their actual energy needs. Secondly, planning should encompass top-down approach to allow for input from energy expert(s) and relevant authorities. Last but not least, values and attitudes embodied in REA's resultant interventions should not be imposed on the rural poor. This would enhance REA's development programmes in meeting the needs of the rural poor on one hand and at the same time realizing specific national development goals (ID, 2012).

Promotion of new renewable energy technologies by outsiders in rural Kenya might not be challenging. This is according to a finding(ID, 2012)that Kenyans are renowned culturally for their willingness to embrace new technologies. However, fundamental understanding of the livelihood strategies, needs and priorities of the poor is vital to avoid RE programmes thatsquander scarce development resources. The above observations could help guide future course of action in rural energy supply.

Importance of RE sources

Versatile and flexible resource: RE technologies can be harnessed into various forms of fuels such as liquid, solid or gaseous fuels. For instance, biomass fuels can undergo thermal chemical conversion into form(s) such as, but not limited to, char, methane, hydrogen, carbon monoxide, methanol, for electricity, heat or transport purposes.

Abundance resource: Unlike fossil fuel resources that are finite, RE will not run out as is from natural and persistent flows of environment occurring in the immediate environment. However, practical RE systems must be matched to particular local environmental energy flows occurring in a particular region.

Regarded as carbon neutral/zero greenhouse gas emissions. RE is a clean source of energy that has much lowerenvironmental impact than conventional sources(Twidell and Weir, 2006). This is supported in economics such that if the full external costs of both obtaining the fuels and paying for the damage from emissions are internalized in the price, RE are cheaper for the society.

RE system manufacture and maintenance requires workmanship thus creating employment and boosting the local economy in form of incomes.

The use of RE reduces dependence on foreign oil supplies and thus guarantees the energy security of a country or region.

However, RE has got some disadvantages. For example, solar power is less effective in cloudy weather while the wind power is ineffective during calm days. However, integrating solar and wind power systems could complement each other during either the calm or cloudy days.

Commercialization and opportunities of RE

Renewable energy supply in sub-Saharan Africa has been necessitated by unmet demand for energy in the need for diversification of energy supplies, as well as by the increasing deleterious environmental impact of fossil fuel use and its limited reserves. In view of the limited resources and potential of RE to meet the energy needs of the rural population, there is need of clear policy and strategy by REA to facilitate and enable optimal commercial exploitation and utilization of RE. The development of RE in rural Kenya requires acceleration by strategic national government with co-operation from both county and constituency levels.

Already, RE has become a business opportunity for some entrepreneurs. Low investments in the design, manufacture and assembly of facilities such as solar panels, solar water heating systems, wind turbines, small hydro-generators, briquette press, to mention but a few, is becoming a major attraction. Similarly, other entrepreneurs who understand the need and future prospects of RE have started RE service ventures such as energy audit, energy efficiency and management, carbon credit and finance, among others.

However, given the substantial amount of capital required to set a RE system or technology, the government through the Ministry of Energy and Petroleum is providing supportive measures. This include the Feed In Tariffs (FIT), whose main purpose is promote electricity generation from RE sources (Ministry of energy & Petroleum, 2014), among others.

Way forward

Following inferences indicates the way forward in the use of RE.

Rapid maturity and commercialization on emerging RE is needed through concerted research and development among all energy stakeholders.

Some areas are already utilizing RE for electricity generation with success. This should build confidence in technology transfer of RE technologies to other areas, especially in the rural areas.

Long term planning based on resource data and reliable technology is fundamental as opposed to short term planning based on political inclination or reasons.

The high initial capital costs should not be the major criteria for energy system selection provided observed and validated viable life cycle measures are in place.

Establishing, strengthening or upgrading the existing institutions to promote public or private funding in the infrastructure and institutions of RE technologies.

Conclusion

Special collaboration is needed amongst various government organs, private stakeholders, investors, institutions of higher learning and NGOs to commercialize REs. This course is not easy but it is desirable. There should be a paradigm shift to long term thinking in terms of energy investments. Renewable energy commercialization can effectively work if long term sustainability of energy supply and energy security is put into consideration. The government should focus on reducing rural poverty and provision of affordable, clean and sustainable energy to the rural poor. This can start with the government expansion of rural energy portfolio to incorporate the RE resources which are cheaper in the long run and requires little maintenance costs.Attaining this goal will help reduce rural poverty as the REs will be made available at affordable prices.

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The Progress of Energy Efficiency and Conservation in Kenya: A Review

Isaac K. Kiunga, Jeremiah K. Kiplagat, Tom F. Ishugah
Department of Energy Engineering, Kenyatta University, P O Box 43844-00100, Nairobi, Kenya
E-mail: kiungaisaac@gmail.com Tel: +254725874130

Abstract

Energy is the key to economic production and economic growth of any nation and community. The energy sector in Kenya is fundamentally dominated by petroleum fuels and electricity especially in the urban areas and commercial sector. Rural communities and the informal sector however, rely mainly on woodfuel. The Kenya Association of Manufacturers (KAM) alongside the Ministry of Energy Kenya established a Centre for Energy Efficiency and Conservation (CEEC) to help institutions and companies to strategize and implement energy saving measures in order to improve their profitability while promoting a clean environment. This in turn would help the country to conserve its energy resources, manage its national energy intensity, preserve the environment and save the scarce foreign currency on energy imports. In the last decade, Kenya has taken several steps towards achieving an energy efficient economy. However, the progress of this program has not been analyzed nor is there a clear evaluation of the impacts of this undertaking. This paper discusses the progress that Kenya has made to date in energy efficiency and conservation. The paper commences with an overview of Kenya's energy sector followed by a discussion on energy usage trends in Kenya. It also highlights various energy policies and their impacts as well as the roadmap to energy efficiency and conservation in Kenya. Finally, the future outlook for energy efficiency and conservation in Kenya is addressed.

Key words: energy efficiency, energy conservation, energy policies, energy intensity

1. Introduction

In Kenya, energy efficiency and conservation was a very rare subject until the year 2000 when the country was stricken by the power crisis (IEAKenya 2000). The Kenyan economy was adversely affected with accrued losses of about KES 540 million in the first month of the power crisis (Kirai 2006). In a study done on 23 developing countries for the period between 1980 and 2005, it was observed that Kenya was among the worst performing countries in terms of energy efficiency and conservation for that entire study period (Zhang, Cheng et al. 2011). It is response to the 1999/2000 power crisis in Kenya that GEF (global Environment Facility) and KAM (Kenya Association of Manufacturers) initiated a joint industrial energy efficiency project that extended from 2001 to 2006 to boost energy efficiency and conservation in the country (Mwangi 2009). The successful progress achieved through this joint project eventually inspired the inception of the Centre for Energy Efficiency and Conservation (CEEC) based at KAM's headquarters and jointly funded by the Ministry of Energy Kenya (Yager 2010). The Ministry of Energy has supported this Centre by a budgetary allocation of KES 40 million annually since 2006 (Yager 2010). This supportive effort by the government has favorably impacted the status of energy efficiency and conservation in Kenya's manufacturing and commercial sector (Kirai 2007).

Energy efficiency and conservation is presently a trending subject matter in Kenya's energy sector (KenyaEngineer 2013) because it is recognized as a key aspect in ensuring energy security, environmental protection and economic success of the country (CCPS-Africa 2013). While energy conservation can be achieved through behavior change (Schipper, Meyers et al. 2005), energy efficiency is mostly influenced by the equipments in use and technology advancement(Anderson and Newell 2004). Energy efficiency and energy conservation have the ability to reduce the excessive exploitation of energy resources by reducing the energy demanded (Wulfinghoff 2007). Thus, there is a possibility to achieve a desired output using much less energy which ultimately leads to fewer emissions from power plants and fewer energy costs hence positively impacting both our environment and our economy (DoE-US 2007).It is estimated that the demand for energy will continue to grow as more people in developing countries rise to the middle income class, with the increasing population (Wolfram, Shelef et al. 2012), and the emergent industrialization (Lee 2005). Thus, there is a need to encourage energy efficiency and conservation than ever before so as to ensure energy security and safeguard the economic growth of the country (Levine, Meyers et al. 1991).The government of Kenya has enacted favorable energy policies to promote energy security in the country. For instance the latest energy policy paper; the National Energy Policy 2014, section five deals with policies and strategies that the government has planned to enhance energy efficiency and conservation in short term (2014-2018), medium term (2014-2023) and long term cases (2014-2030). Energy Policies have revealed a positive impact in energy efficiency and conservation if stringently implemented (Yang 2006). Despite the enormous benefits that are associated with energy efficiency and conservation, implementing energy saving and energy efficient technologies is still a monstrous challenge in Kenya due to technical, financial and market barriers amongst other challenges (MoEPKenya 2014). However, there are a number of significant strides that the country has made so far in the advancement of energy efficiency and conservation programmes especially through enactment of various energy policies. Therefore, this paper evaluates the progress and the impacts of energy policies on energy efficiency and conservation in Kenya and discusses the challenges and successes experienced.

2. An overview of Kenya’s energy sector

In 2012, the major forms of energy used in Kenya were found to be wood and biomass, 68 %, petroleum and other fossil based fuels, 22%, and electricity, 9% (Energypedia 2013). Wood fuel is predominantly used in the rural areas because it is readily available and affordable than other sources of energy (Kiplagat, Wang et al. 2011). Implementing energy efficiency and conservation measures can greatly reduce the pressure on Kenya’s energyresources.

2.1 Grid connected electricity and usage trends

By July 2013, Kenya was being powered by an installed capacity of approximately 1,576 MW of electricity (KenyaEngineer 2013). This is up from an effective power generation rated 1,306 MW by 2011 and the corresponding system peak demand rated 1,178 MW (KenyaEngineer 2013). During this period, the major sources of electricity in Kenya were hydropower, thermal/Diesel power plants and geothermal power generation. Cogeneration and wind power were the minor sources of grid electricity in Kenya. Figure 1 shows the Kenya’s electricity generation/supply by source from the year 2008 to 2011 in Gwh units (KNBS 2012). It can be deduced that the increased power generation impacted positively on the growth in Kenyan industrial sector consequently impacting the Kenya’s economic growth to a record high of more than 10% in 2010 (WorldBank 2012). This is also supported by the fact that the biggest sector-wise consumer of grid electricity in Kenya during this period was the large and medium commercial businesses and industries (KNBS 2012). These sectors continued to increase in their consumption as seen in Figure 2 where the consumption grew by approximately 20% from year 2008 to 2011. The second biggest consumer is the domestic and small commercial sector where electricity is mainly used for lighting and powering electronics (KNBS 2012). The demand for electricity is increasing each year as a result of economic growth and developments in the industrial sector which is constantly in need of power (Ihuthia 2012). This is also attributed to the rural electrification which has been in the rise for the last 8 years.

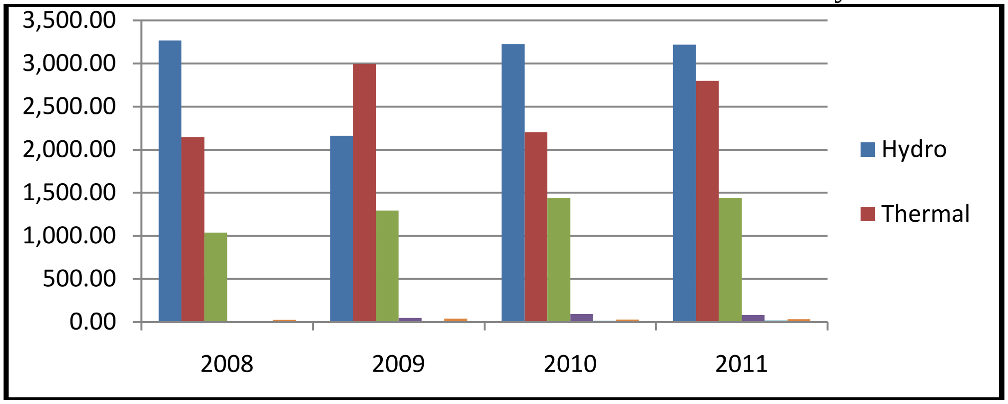

Figure 1: Kenya's electricity generation by each source from the year 2008 to 2011 in Gwh units (KNBS 2012).

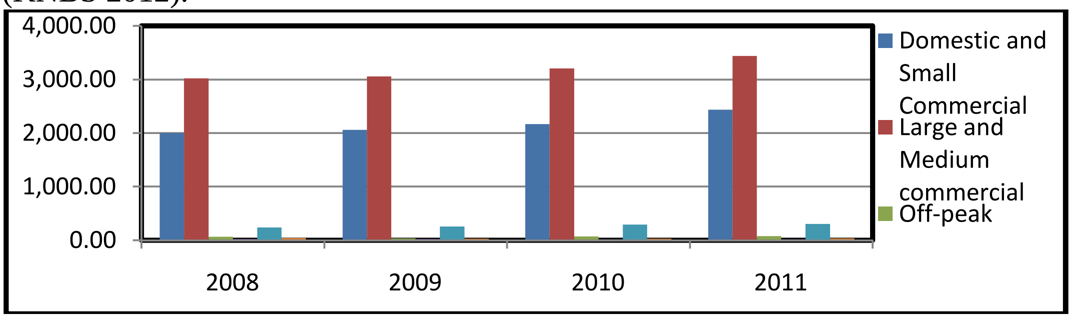

Figure 2: Electricity Consumption by each sector since year 2008 to 2011 in Million Kwh units (KNBS 2012).

The projected peak demand will grow up to over 16,905 MW by the year 2030 which is almost 10 times of the current peak demand and will require an installed capacity of about 21,620MW. Therefore, it is crystal clear that with the increasing number of grid connected customers, the system's peak demand will always be on the increase hence increasing the pressure to invest in electricity generation. In response to the constantly growing peak demand, the Kenyan government engaged a group of experts to study and produce an extensive plan on the energy demand and supply portfolio for the country so as to prepare for the increasing peak demand up to the year 2030 (MoEPKenya 2011). The plan was developed on a least cost basis so as to encourage investment in electricity generation from the selected energy resources. Figure 3 shows the planned electricity supply from various sources by 2030 as established in the updated least cost power development plan for Kenya (MoEPKenya 2011). However, if energy efficiency and conservation measures are put into practice, the system peak demand may be brought under control.

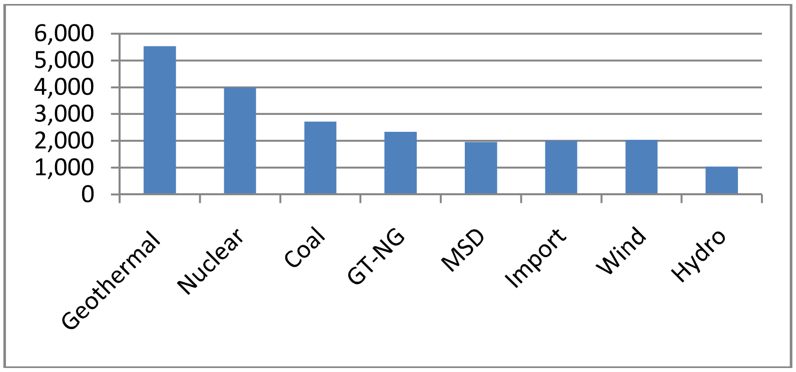

Figure 3: Electricity supply by source in the year 2030 (MoEPKenya 2011).

2.2 Wood and biomass energy

Woodfuel is the major source of biomass energy in Kenya (Kiplagat, Wang et al. 2011). It contributes approximately 68% of the total energy use in Kenya. Wood fuel constitutes about 90% of the household energy use in the rural Kenya. In the urban households, charcoal fuel is the major biomass energy where about 82% used it for cooking as compared to 34% of rural charcoal users (Energypedia 2013).It is estimated that the biomass fuel deficit will increase to about 33.9 million tons by the year 2020 in business as usual scenario(Githiomi and Oduor 2012). This deficit is associated with the ever increasing demand for woodfuel which puts a strain to our existing forest cover the main source of fuelwood(Bailis, Pennise et al. 2004). With biomass being the major source of energy used for cooking and water heating, its conservation is fundamentally dependent on the biomass stoves that are currently in use (Kabage 2012). The most common biomass cooking stove is the open fire ‘three stones’ biomass stovewhich is mostly used in the rural areas of Kenya. These kind biomass stoves are common because they are readily available and especially affordable for everyone. However, the improved charcoal stoves and the improved firewood stoves are more energy efficient than the open fire type hence, they have now been introduced in the Kenyan market. These improved biomass stoves have proved to be the solution to biomass energy efficiency and conservation if well adopted and utilized(Kahurananga April 25, 2013).The improved charcoal stoves programme was initiated in 1981 by the Ministry of Energy Kenya to enhance wood fuel conservation. These stoves are commonly referred to as Kenya ceramic Jikos. They have been widely circulated and used in Kenya since they are more energy efficient and they have helped in conservation of wood fuel energy(Kiplagat, Wang et al. 2011) The Government of Kenya has also come up with a proposal to make it mandatory for the schools and institutions to adopt the use of energy saving Jikos in order to conserve biomass energy and consequently our forest cover.

2.3 Petroleum and other fossil fuels

Petroleum fuel is the most significant energy resource for commercial use in Kenya.it is mostly used in transport sector, thermal power generation, and in industrial and commercial sectors(Kianji 2012).Kenya utterly depends on oil imports. However, soon Kenyawill be relieved from costly oil imports when Tullow oil in Turkana succeeds in drilling oil and refining it locally. In January 2014discoveries,Tullow Oil Company announced that oil reserves in Turkana all have an estimated capacity of 1 billion barrels. This optimistic forecast if achieved will significantly increase the quantity of petroleum fuels in Kenya hence lower costs of petroleum products and make it possible for the government to save foreign currency(Waweru 2014).In Kenya’s petroleum history, the highest shifts in amounts of petroleum products imported was realized in 1998-2000 (FactFish 2014, Gachie 2014) when Kenya faced power crisis consequently increasing the crude petroleum importation to approximately 2,157,700 tons (KNBS 2000) to cater for thermal power generation during this power crisis period. Kenya also relies entirely on coal and coke importation to meet its energy needs in industrial and commercial sectors(Okech 2013). The trend of coal importation in Kenya has been on the rise with importation by year 2012 being almost twice the amount in the year 2008. This is attributed to the increase in number of manufacturing industries(KNBS 2013).

3. Kenya's Policy framework in support of Energy Efficiency and Conservation

3.1 Sessional paper 4 on energy, 2004

This is the first energy policy paper to be written in Kenya in response to the power shortages that hit the country in the years 1999 and 2000 which adversely affected the country's economic performance (MoEPKenya 2004). The government recognized the need for energy efficiency and conservation and they put down measures to enhance energy management in several sectors of economy.This policy paper suggests that the government, through ministry of energy, will enhance energy audits and provide advisory services to institutions and companies. Further, the government was empowered to instigate a national level "centre of excellence" for energy efficiency and conservation to promote, guide and implement energy efficient technologies that would promote industrial cost effectiveness via energy efficiency and conservation measures(MoEPKenya 2004).

3.2 The energy act 2006

This is an act of the parliament that was meant to amend and also consolidate the laws concerning energy, facilitate the establishment of Energy Regulatory Commission (ERC) and Rural Electrification Authority (REA).Under this policy, the Energy Regulatory Commission (ERC) is charged with the responsibility to designate factories and industries according to their types, the ways they utilize energy and their quantities of energy they consume. This policy empowers the commission (ERC) to inspect whichever buildings, factories and facilities as per the standards, procedural guides and the criteria stipulated in that Act, so as to ensure observance to energy conservation measures and use of energy efficient systems(MoEPKenya 2006).

3.3 Energy management regulations, 2012

This policy was mainly drafted to stipulate the necessary procedures in energy efficiency and conservation. Under this, the owner or occupier of a facility is compelled to develop an energy management policy and file it with the commission within a period of one year (MoEPKenya 2012). This policy paper also makes it mandatory for the occupier or owner of any facility to initiate energy audit for the facility and file the energy audit report with the commission within six months from the end of its financial year in which the audit was done. This should be done at least once in every three years. The owner or occupier of the facility is also required to develop an energy investment plan for extending to a period of three years from the time of audit and showing energy conservation proposals for all that period. This plan should also be filed with the commission. This policy paper makes it mandatory for all buildings using any form of energy to be audited and come up with ways and measures to conserve energy. This policy provides a clear focus on energy efficiency and conservation in what is termed as energy management

3.4 Impacts of the energy policies

Energy policies and energy planning are key elements in the development of energy sector as well as in promoting energy efficiency and conservation (Ellis 2010). As a result of the energy policies in Kenya, the government alongside the Kenya Association of Manufacturers (KAM) established a government and foreign agency funded Centre of Excellence in Energy Efficiency and Conservation (CEEC) based at KAM's offices.From the year 2001 to 2006, GEF-KAM was able to assist the private enterprises in commercial and industrial sector to increase their energy efficiency and conservation so as to reduce their energy costs. By the year 2006, they had so far helped the industries to save approximately 155,400 Toe valued at US$ 36 million monetary savings and steer clear of 580,000 tons of carbon emissions equivalent (Kirai 2007). During this period, GEF-KAM managed to train over 1000 personnel from various enterprises on issues concerning energy management (Kirai 2007). The Kenya Energy Efficiency Accord is another milestone that KAM initiated in September 2011 which saw 19 member companies of KAM sign to this program.The combined saving from the year 2010 to January 2012 was approximately 17,400 GJ which equates to KES 50 million.Ten other companies under KAM decided to join the Accord in November 2012. Another impact assessment was done in September 2013, and results showed that all the companies in this Accord realized combined saving of about 46,000 GJ which equates to KES 132 million within a period of two years. In just two years, some companies actually managed to reduce their energy intensity by approximately 40% which surpassed their earlier target of 15% which they committed to achieve in five years (CCPS-Africa 2013). Since its inception in 2006, CEEC has helped KAM member companies to implement the recommended energy saving measures which have enabled them altogether to save approximately 168 MW of energy by year 2013, equivalent to monetary savings of KES 9.35 billion as well as contributed to environmental protection and increased energy security(KenyaEngineer 2013)

4. Roadmap to Energy Efficiency and Conservation

4.1 Energy Efficiency and Conservation at the supply side and the future outlook

On the supply side, the government is dedicated to promoting and encouraging energy efficiency and cost effectiveness in extraction of fuels, energy conversions and in distribution (Mwangi 2009).Adoption of new energy efficient conversion technologies can have a large impact in reducing the energy intensity of the country (Heintzelman 2009). For instance, new biomass conversion technologies can improve on supply side efficiencies especially where biomass is used boilers for power generation or where it is converted to biofuel for use in diesel engines. Another major improvement on the supply side energy efficiency would be focus on reducing transmission and distribution losses. The Kenya Power and Lighting Company (KPLC) is committed to reducing transmission and distribution losses are by at least 0.5% every year (Mwangi 2009).

4.2 Energy Efficiency and conservation at the end user and the future outlook

This is to make sure that the use of energy at the consumer level is more efficient and economical. The Energy Management Regulations, 2012 is one of the government policies that was put in place to enforce end user energy efficiency and conservation (MoEPKenya 2012). In another policy, Energy Act 2006, it stipulated that new large size buildings should integrate features that promote energy efficiency and conservation especially in lighting and ventilation systems (MoEPKenya 2006). The Energy (Solar Water Heating) Regulations of 2012 also recommended the use of solar water heaters for all buildings using more than 100 liters of hot water so as to avoid wastage of electricity in water heating systems for residential, hotels, schools, hospitals and other institutions (MoEPKenya 2012). In the year 2010, the KPLC embarked on a plan to enhance energy efficiency in residential houses by rolling out 1.25 million CFLs (Compact Fluorescent Lamps) to control the system peak load. This initiative was also meant to create awareness in energy conservation and sensitize the public on the benefits of utilizing energy efficient technologies in lighting. This project was very successful and managed to reduce the peak demand by approximately 50MW hence the government was delighted to roll out the second batch of 3.3 million CFLs to reduce peak demand even further (Ihuthia 2012).

5.0 Conclusion

The energy sector is playing a major role in transforming Kenya to an industrialized middle income country. There is an increase in the number of people being connected to the national grid every year and so is the amount of fossil fuels being imported into the country. The answer to providing clean, reliable and affordable energy not only relies on increasing the energy generation portfolio but also in ensuring energy efficiency and conservation to ensure that energy is being used economically and efficiently. This will mean that the cost of converting energy to GDP is lowered, consequently lowering the countries energy intensity. The government has come up with various energy policies which compels various institutions and individuals to implement energy efficiency and conservation measures. The impact of these policies is already being felt and there has been a great progress in energy efficiency and conservation as a result of these policies. For instance, The Centre of Energy Efficiency and Conservation has played a major role in helping KAM member companies to save approximately 168 MW which equates to monetary savings of KSh. 9.35 billion in the last eight years. This progress is very impactful to the environment and the Kenya's economy.

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Issues and challenges facing sustainable energy future for developing nations

Fred .T. Ishugah, Jeremiah .K. Kiplagat, Isaac .K. Kiunga
Department of Energy Engineering, Kenyatta University, P.O Box 43844-00100, Nairobi, Kenya
Email: Ishugah.fred@ku.ac.ke

Abstract:
Energy continues to be the pivot of economic and social development of all nations around the world. Although it has brought great economic prosperity, the way it is produced and used is inefficient and has adversely affected local, regional, and global environments. This paper extensively brings out different issues in energy exploration and exploitation challenges particularly in developing nations and tries to put forward some remedial measures to allow for sustainable development. Support has been expressed for renewable energy systems, owing to their more favorable environmental qualities and ease of access in developing nations.

Keywords:
Energy resources, Developing nations, Renewable energy,Sustainability

Introduction

Among many resources, energy resource plays a vital role in the economic and social growth and progress for any nation.Many developing countries are however facing serious issues of lack, inadequate and interrupted energy supply. These issues have crucially affected developing countries economic growth both on the short and long-term sustainability planning.Availability of energy resources that are affordable, easily accessible, and environmentally friendly have also been an issue many developing countries are struggling with. In addition most developing countries rapid population growth and the improvement in the living standard have also come with a cost in planning for sustainable energy supply.

According toMirza and Monirul,(Mirza 2003) climate change has been identified as one of the greatest challenge by all the nations, government, business and citizens of the globe. The threats of climate change on our green planet 'Earth' demands that renewable energy share in the total energy generation and consumption should be substantially increased as a matter of urgency. Future generations may well puzzle why we knew about the problem but still didn't take steps to tackle it (Crick and Sparks 1999).

Due to predominance of fossil fuels in the generation mix, there are large negative environmental externalities caused by electricity generation. So it has become imperative to develop and promote alternative energy sources that can lead to sustainability of energy and environment system. Renewable electricity has become synonymous with CO_2 reduction. Present communication provides a brief description about such alternative and sustained energy sources, i.e., renewable energy resources, their potential and achievements.

As renewable energy continue to stand as a more established and mature technology to offset large proportion of power, especially in many developing countries, it is important to note that more still needs to be done to exploit its full potential. Energy resources and sustainability in developing nations is now being studied by many researchers (Dincer and Rosen 1999, Damtoft, Lukasik et al. 2008, Ahmad, Yasin et al. 2011), with many focusing on the renewable energy and the environment(Panwar, Kaushik et al. 2011).

As energy resources, exploration and use in developing countries come under increasing scrutiny, especially employing renewable energy as part of the energy solutions, it is therefore timely to consider renewable energyresources suitability and its exploitation technology for developing nations. This article, therefore, provides a comprehensive knowledgereview on different issues in energy exploration and exploitation challenges particularly in developing nations and tries to put forward some remedial measures to allow for sustainable development. It is expected that this review will be useful for researchers as well as professionals in the energy field, and related planners in developing nations.

Energy resources supply and use in selected developing countries

Renewable energy sources have often been avoided by many developed and developing countries. This is not only as a result of politics but also backed by economic constraints in various countries. The argument frequently put forward is that renewable energy is mostly intermittent and expensive source of energy. For instance, china has increased coal and oil usage to meet its energy demand for its vast manufacturing sector with thousands of industries. Coal is the main source of energy in china (Tverberg 2012). The figure 1(below) shows the trend of energy consumption by source in china.

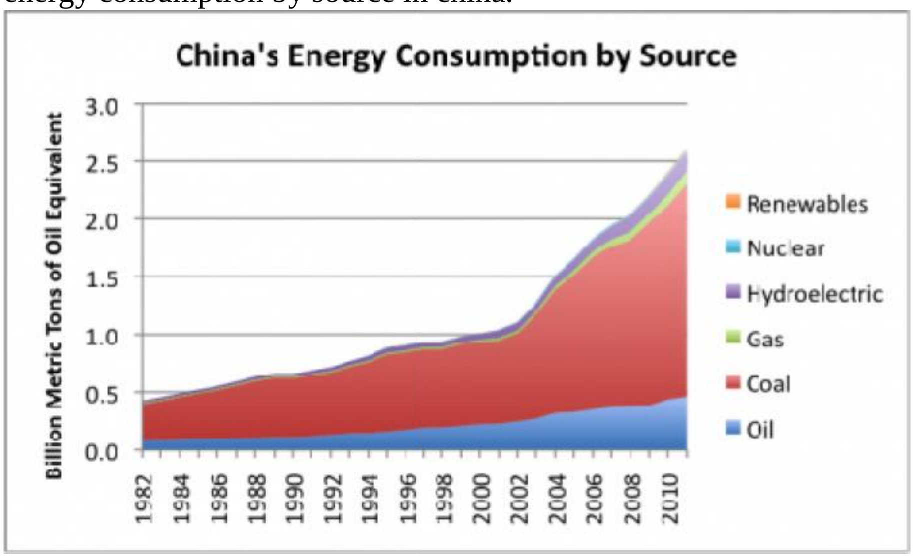

Figure 1 China's energy consumption by source from 1982 to 2010 (Tverberg 2012)

On the other hand, Kenya's energy sector and the energy portfolio are also expanding so rapidly. The current power sources in Kenya total to about 1,800 MW and are mainly hydro, thermal and geothermal and little supply from the renewables. However, the expected supply by 2030 will include other sources like solar, wind and nuclear power in significant quantities(MoEPKenya 2011),as shown in figure 2.

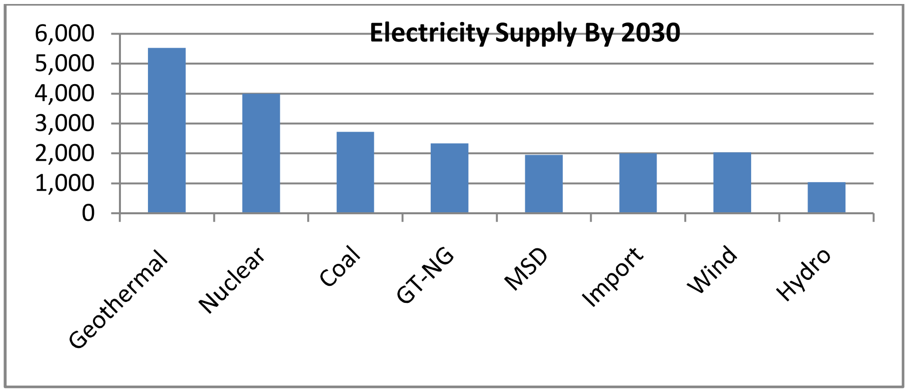

Figure 2 Electricity supply by source in the year 2030 (MoEPKenya 2011).

Energy challenges facing developing nations

Generally, majority of the people living in developing countries lack adequate access to the essentially clean and modern energy services (Ahuja and Tatsutani 2009). In addition, despite the inadequate energy infrastructures in these countries, they also need to concurrently contribute in the global switch to other cleaner and low emissions sources of energy (Jefferson 2008). Therefore, it is crystal clear that in developing countries, to achieve a sustainable energy future, there has to be a double fold of tasks against these challenges to propel them to a prosperous energy future than it would be in the developed countries (Armaroli and Balzani 2007). Some of the challenges that developing countries face towards the attainment of a sustainable energy future are discussed herein.

3.1 High and fluctuating energy prices especially for fossil fuels

Developed countries have used fossil fuels to conventionally power their economies for a couple of centuries since industrial revolution (Bhavish Patel 2012). These economies have expanded rapidly with increased use of fossil fuels hence most developing countries consider that energy from fossil fuels is the key to growth of their economies. While persistent use of fossil fuels have severe impacts like depletion of fuel reserves, environmental concerns and global warming (Ellis 2010), also the prices of these fossil fuels have also continued to increase significantly (He, Wang et al. 2010). For this reasons, developing nations have been constantly exposed uncertain and unsustainable energy future. It is reported that in 2005, oil imports bills in some developing countries was nearly twice of the official development assistance that those countries had received for that fiscal year (TWAS 2008) thus financially straining such economies and putting a weighty burden on energy supply (TWAS 2008).

3.2 Technological challenges

Approximately 80% of the global carbon emissions emanate from energy related activities (Barton 2007). Carbon emissions are causal agents of climate change. To mitigate this impact, countries need to invest in low emissions energy technologies, energy efficiency improvement and in tapping renewable energy sources which have little greenhouse gas emissions (Forsyth 2014). However, most of these commendable technologies are still under development, thus they are not as reasonably priced as the case of fossil based technologies which have become of age.

By the year 2008, around 40% of the population in developing countries lacked access to clean modern energy services (TWAS 2008), thus the most urgent need in these countries is increasing that access to clean energy services. However, there are other competing and urgent services in these countries; health, adequate water and food for their citizens. Since budgetary allocation in most developing countries is strained, the more pressing needs of health, food and water are given first priority leaving energy access remaining a persistent challenge (Friedmann 1976, Kaygusuz 2012). Therefore, both technological and financial frameworks ought to be strengthened to scale up energy investments in clean and renewable energy technologies for a sustainable energy future in these developing countries (Kaygusuz 2012).

3.3 Inefficiency in energy demand management

Demand side management has the advantage of shifting energy demands to off peak hours so as to decrease the peak demand and increase off peak demand thus stabilizing base load supply of power, reducing energy wastage during off peak , reduce the cost of storage and reduce the investments in more power plants and networks to meet peak demands (Palensky and Dietrich 2011). Most developing countries face this challenge of energy demand management notwithstanding that it is an important factor in ensuring a sustainable energy future. Energy efficiency and energy consumption patterns can help achieve energy demand side management. However, most energy efficiency technologies are quite expensive especially in developing countries while the financial support for energy efficiency and conservation is inadequate. In addition, the policies and regulation on energy demand management are still deficient (Mahdavinejad, hashemi Rafsanjani et al.).

3.4 High capital investment cost for efficient energy systems

An efficient energy system will guarantee that there is a balance between demand and supply of energy while at the same time maximizing the efficacy and output from an energy system by minimizing losses (Martin, Worrell et al. 2000). Thus, such a system ensures that there is power when it is actually needed.This can be achieved through distributed power generation (Willis 2000), energy storage systems (Ter-Gazarian 2011), integrated power and smart grid systems (Brown 2008). With the introduction of clean and renewable energy resources in power generation, the best way to make this more sustainable is through a shift to localized power generation. Thus, homeowners, plant managers, and businessmen will find it easy to produce own electricity at their local sites rather than depend on buying the readymade electricity from large utility systems (Willis 2000). Energy storage systems is also an essential factor that will increase the generation capacity and enhance sustainable harnessing of power from primary energy sources whose supply is intermittent and hardly ever match with the consumer demand patterns (Ter-Gazarian 2011). In power distribution, the future success of efficient energy systems will essentially depend on the smart grid systems and its ability to provide real time net pricing, increased reliability and enhanced energy management (Brown 2008).

3.5 High project development to investment cost ratio

The ratio of project development costs to project investment is also higher for renewable energy projects. This is due to the nature of renewable energy projects, which are often dispersed, small in scale and lack established infrastructure to assist in project development. Legal, regulatory and engineering transaction costs are also generally higher, more complex and do not benefit from the economies of scale common to large conventional projects.

3.6 Difficulty in guaranteeing project cash flow

Investing in sustainable energy is an expensive undertaking that requires an enormous investment. Guaranteeing a project’s cash flow is an essential element needed to secure project financing. To guarantee costs usually requires long-term fuel supply contracts and possibly a plant-operating contract, which has not been done effectively in many developing countries. For revenues, this suggests that a solid power (or energy services) purchase agreement is a necessary element. Renewable energy projects often have to deal with many fuel suppliers (as in the case of solar, wind, hydro, etc.) and are not able to guarantee that the “fuel” will be available when needed since it may depend upon environmental conditions. Additionally, renewable energy projects tend to have multiple "power purchasers" most of which are not in a financial position to provide enforceable long-term guarantees to purchase the output of the project.

3.7 Weak basis for non-recourse financing

In many developing nations, there is usually a limited number of established organizations in terms of experience and scale of establishment. The available small, independent and newly established renewable energy project developers often lack the institutional track record and financial inputs necessary to secure non-recourse project financing.

3.8 Inaccurate perception of risks

Many renewable energy technologies are newly commercial and are, subsequently, not widely known among project financiers, especially in developing countries. Moreover, information about renewable energy systems is not readily available and accessible to potential investors, although this is changing rapidly with greater Internet access. The reality is that many renewable energy technologies are rapidly making commercial inroads in the marketplace.

3.9 Weak project developers

On a global scale, renewable energy projects tend to be developed by smaller entities with weak financial positions. They are frequently unable to leverage the financial resources needed and as a result are unable to attract equity investors or secure debt financing in many developing countries.

Remedial measures to offset these challenges

4.1 Increase integration, adoption and utilization of renewable energy resources

Increase integration and adoption and utilization of renewable energy resources, in developing nations, as compared to fossil fuels can help in a number of issues.There is a need to increase the importance of renewable resources for use in energy supply. The renewable energy is environmental friendly since there is very little carbon emissions as compared to burning fossil fuels for energy provision. In addition, the renewable resources are either so huge to be exhausted in use or else their rate of replacement is so high as compared to their utilization rate. They are thus replaced during one's life time and sometimes immediately they are used.

4.2 Observing energy efficiency and energy conservation measures

It is also vital to ensure that the energy supplied is used meaningfully and as sparingly as possible. Use as less as possible and as needed. Use energy smartly without wastage. This can be achieved through use of energy efficient processes and systems to reduce energy wastage. Reduced energy wastage means that energy is preserved for future use in the sense that less energy will be produced since the little that is available is used efficiently. This will ultimately lead to reduced energy generation hence less carbon emissions. This means that energy efficiency and conservation indirectly leads to reduced environmental climate change.

4.3 Clean inventions and innovations

The world needs to shift its new inventions to the area of providing clean energy. More innovative ideas and projects relating to clean energy generation and utilization are required to save our planet from carbon emissions. Innovations are much needed in several sectors of the economy utilizing much energy including transport sector, industrial sector as well as the renewable energy sector.

4.4 Strengthening of Policy and regulatory framework on new technologies on renewable energy sources

Government incentives on construction of renewable energy power plants, distribution and transmission lines will also enhance adoption of such sustainable energy technologies. The governments need to revolutionize energy production and electricity generation as a path towards sustainability.

4.5 Strengthening of carbon trade and pricing

The global society should also strengthen carbon trade and pricing so as to discourage carbon emissions and avoid its release to the environment. Climate change poses one of the greatest local and global challenges and threatens to roll back decades of development and prosperity. Pricing carbon is in developing nations is inevitable if they are to produce a package of effective and cost-efficient policies to support scaled up mitigation.

Conclusions

Although energy resource utilization have been known to play a vital role in the economic and social growth and progress in many nations, most of the developing countries are, however, facing serious issues of lack, inadequate and interrupted energy supply. These issues have crucially affected developing countries economic growth both on the short and long-term sustainability planning. Increased adoption of use of renewable energy in developing countries can stand as a more established and mature technology to offset large proportion of power. This however will need to be done in a more sustainable way to exploit its full potential. A comprehensive knowledge on different issues in energy exploration and exploitation challenges particular to different developing nations needs to be analyzed. The analysis can help lay grounds in trying to put forward some remedial measures to allow for sustainable development in these nations.

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The Potential of Efficient Improved Mud-Brick Cook Stove in Cameroon

[1]F.H. Abanda, [2]E.Cole and [3]B. Mempouo
[1]Oxford Institute for Sustainable Development, Department of Real Estate and Construction, Oxford Brookes University, Oxford OX3 0BP, UK

[2]Better World Cameroon

[3] Association pour la Recherche et la Promotion de l'Energie Durable en Afrique Centrale (ARPEDAC), Avenue John Ngu Foncha, Nkomkana 2, Yaoundé II, BP 5834 Yaoundé, Cameroon, www.arpedac.org

*Corresponding author: fabanda@brookes.ac.uk

Abstract
In most Africa countries, cooking is a dirty and time-consuming activitythat involves feeding fuel such as wood, charcoal, or coal for a fire. Globally, some 500 million households with more than 70% in Africa depend on burning solid fuel to meet their cooking, heating, lighting, and other household energy needs. The wanton exploitation of wood fuel is having so many negative impacts on many households in Cameroon. In the Central Africa region including Cameroon about 80-90% of the population has limited access to modern forms of energy, such as electricity, and relies on traditional biomass such as wood and agricultural residues for cooking and heating. There is an urgent need to investigate more efficient cook stove technologies that have very minimal or no impact on the environment and households. In this study, an improved mud-brickcook stove was designed and tested in a typical family house in Cameroon. To ensure the acceptability and sustainability of the technology, the rural dwellers were involved in the design and implementation. The performance of the stove was compared with that of traditional 3-stone fireside common in most rural households in Cameroon.

Key words: Cameroon, cook stove, efficiency, solid fuel

Background
Global increase in population has led to an increase in the demand for basic services such as water, energy, houses and infrastructure. Amongst these, energy is one of the most pressing needs in developing countries. In most Africa countries, cooking is a dirty and time-consuming activity that involves feeding some fuel types such as wood, charcoal, or coal to produce fire. Globally, some 500 million households with more than 70% in Africa depend on burning solid fuel to meet their cooking, heating, lighting, and other household energy needs (ARPEDAC, 2014). Compared to other regions of the continent, Central African region has limited basic infrastructure. Access to electricity remains precarious and falls far short of Africa's level. The energy consumption is 12.5 kWh per inhabitant against 17.3kWh for the continent (ECCAS 2025 Vision, 2014). Also, electricity provided by main electricity suppliers has been noted for regular and constant power cuts. This is further exacerbated by high electricity cost that is often not affordable. In some regions, there is total lack of gridlines to supply electricity and the cost to pay for it is usually exorbitant and cannot easily be borne by an individual. Perhaps, partly

because of these challenges, Cameroon is one the countries with a high dependence on solid fuels. Solid fuel refers to various types of solid material that are used as fuel to produce energy and provide heating, usually released through combustion. Solid fuels include wood, charcoal, peat, coal, hexamine fuel tablets, and pellets made from wood. Eighty three percent of the population in Cameroon use solid fuels for cooking meals daily (GAFCC, 2013). The use of solid fuel has so many health related impacts. Furthermore, wood commonly used, is not sustainably harvested and there are reports of scarcity and women now have to travel very long distances to fetch for wood. About 2.7 million families, who depend on this quickly depleting resource, often walk an average of 3 hours a day to collect wood or spend up to 1/3 of their annual income to cook for their families (EFC, 2012). Cooking over a 3-stone fire inside the home is the equivalent of burning 400 cigarettes an hour and releases toxic smoke and emissions which mostly effect women and children (EFC, 2012). According to Global Health, inefficient cook stoves are said to be the largest environmental threat (GEC, 2012).

It has become imperative to investigate alternative ways of providing energy that is environmentally-friendly, affordable and socio-culturally accepted. Clean cook stove technologies have emerged and are gradually being supplied in Cameroon. However, some of these technologies have not been documented in academic literature. As such many aspects or factors (e.g. efficiency) which are important with regards to making decisions about their uses are scarce. The aim of this study is to report on an innovativemud-brickcook-stove designed for use in Bafut, a village located a few miles fromBamenda, the North-West regional capital of Cameroon.The objectives are to:
investigate the design of a mud-brickcook-stove
investigate performance of sustainability factors
compare the performance of the mud brickcook-stove to traditional 3- stones fireside
propose recommendations for future study.

An overview of solid fuel consumption studies and projects
Studies about solid fuel consumption in Cameroon are scarce. Njiti and Nkemcha (2003) conducted a survey of fuel wood and service wood production and consumption in Garoua, Cameroon, and its rural environs. Neba (2010) investigated the problems of wood fuel yield, availability and harvest in the Tubah mountain forest, Cameroon.Vitali et al. (2013) investigated the efficiency of rice husk stove in rural Logone Valley (Chad/Cameroon). Vaccari et al. (2012) conducted a comparative study to determine the fuel and cost savings of two Centrafricain wooden stove models, traditional 3-stone fire and a gas stove. Vitali and Vaccari (2014) examined the various dissemination models of improved stove in the Logone Valley (Chad, Cameroon). Based on the literature there are many different types of solid fuel technologies in use in Cameroon, with the traditional 3-stone firesidebeing quite common. InMbouda, Dschangand Yaoundé cities, Cameroon, around 90% of people use wood for cooking on traditional 3 stone fires that are both highly inefficient and a cause of indoor air pollution. Most people in these cities purchase their wood for cooking, which means that very little of the household budget is left over to invest in a cleaner, more efficient cook stove. ACREST and ARPEDAC havemade efforts to address this issue by developing a locally made improved stove (Figure 1:b and c), based on simple, effective cleaner technology made of ceramic insulation and metal frame. ACREST and ARPEDAC stoveswere compared with the traditional 3-stone fireside cook-stove and the results shown that those stoves areenergy efficient and can save up to about

60% of firewood andthey could last more than 5 years with little maintenance (ACREST, 2014).The University of Yaoundé 1 in Collaboration with ARPEDAC has carried further scientific investigations on ARPEDAC's improved stove using the modified version of the well-known Water Boiling Test (WBT) in ARPEDAC's laboratory (Figure 1: c). The kitchen indoor air quality (IAQ) checks, flue gas analyser measures, logs ambient carbon monoxide (CO) and carbon dioxide (CO_2) levels have also been investigated and compared with the conventional 3-stone fireside cook-stove (Mbieji, 2013).

3-side firestone

ACREST's improved stove under testing condition(ACREST,2014)

ARPEDAC's improved stove under testing condition(ARPEDAC,2014)

Figure 1: Some selected sample solid fuel cook stoves in Cameroon

What emerges from the preceding paragraphs is that, there is a lack of systematic and coherent studies about the different solid fuel cook stoves in Cameroon. Also, there is paucity of data and information about solid fuel consumption technologies that can be used to make informed decisions about their uses. While a few studies have conducted comparative studies about different improved cook stove technologies, such studies are often technical with focus on efficiencies or technical performance. Although, this is already great, there is however a greater need to consider other local constraints especially if the needs of the local dwellers have to be met. Vitali and Vaccari (2014) concluded that the dissemination of stove models should consider local constraints. Other softer factors should be considered. For example, are the wood-cook-stove acceptable and affordable?

In addition to the findings from the literature review as discussed in the preceding sections, observational studies were conducted in some households in Bamenda. It emerged that, women use large, heavy cast pots daily to prepare large quantities of food for their families. In the kitchens, the walls are blackened and dark during cooking. Even modern homes have an outside open-fire kitchen, in addition to a gas burner. There is a huge amount of energy loss as a result of cooking in the open. Also small energy efficient stoves are inadequate for the big pots used by households in Cameroon. Our proposed mud-brickstove takes into account all these challenges.

The proposed Ndanifor Permaculture Ecovillage Project

Better World Cameroon[2] is working with Bafut Council in supporting the development of a plan for sustainable growth and development of the region. The organisation's aim is to strike a balance between farmland, housing, and commercial areas. Ndanifor Permaculture Eco village (NPE) is a Permaculture Demonstration Site and Center for environmental education and sustainable food production. NPE is a demonstration site and constitutes part of the Eco-Village Vision for 2020 of Bafut. The improved cookstove project is one of the projects on NPE. One of the cookstove is the innovative mud-brick cook-stove (Figure 7) recently built in some homes in Bafut.

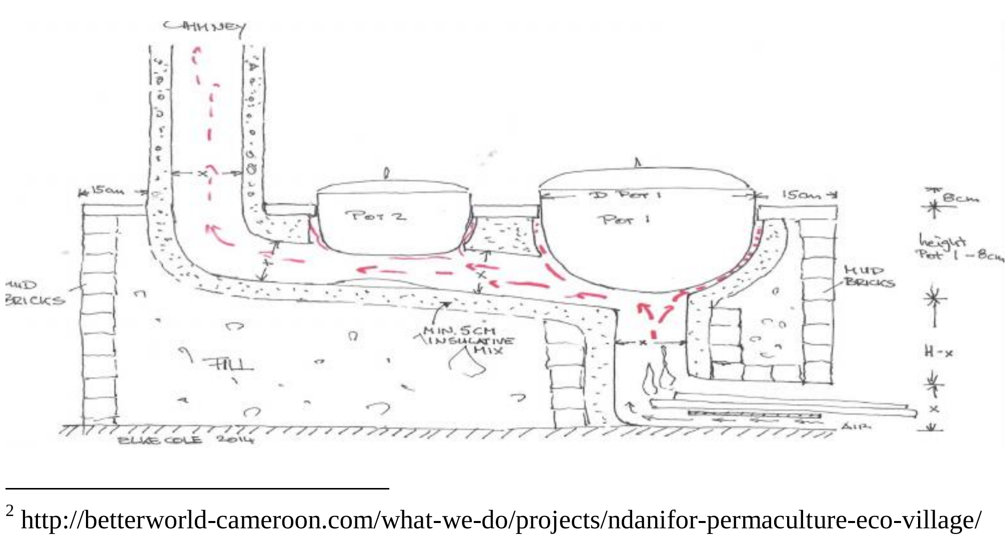
Apparatus and procedure

Description of the mud-brick-cook-stove

The concept of the mud-brick cook-stove is enshrined in the permaculture principles. The materials used for building the stove are mud-bricks, clay soil, saw dust and sand. Other than sand, brought from a different location, all the other materials are sourced from the NPE yard. Water is used for mixing mortar for binding the bricks.The mud-brick cook stove construction materials are available in any community that has clay soil and can be made using limited tools, only requiring a knife, a metal pot and a small hole.

4.2 Description of the design process

The main tools used for the construction of the stove are: a tropical hoe to dig and mix clay, a cutlass (machete), buckets and measuring tape. If a measuring tape is not available, body measurements techniques (e.g. width of hands) are used.Four design steps are discussed. First, the volume of the largest pot that will be used on the stove is determined.The volume relates to the size of combustion chamber and heat path through the stove. This can be looked from a simple chart by Kabuleta (2004). Second, the width of the stove is determinedfrom the diameter of the pot plus insulation plus bricks. Third, the length of the stove is the sum of the first pot plus a second, smaller pot, plus chimney plus edges and channels.Finally the height of the stove is determined as illustrated in the sketch in Figure 2.



2 http://betterworld-cameroon.com/what-we-do/projects/ndanifor-permaculture-eco-village/

Figure 2: Cross-section of mud-brick cookstove

Eleven steps are involved the building of the stove. i.Prepare a 1:1 (by volume) mix of clay and fine sawdust(estimated 4 wheelbarrows of clay) and a clay mortar mix. ii.Laythe positions of pots on the ground. iii.Set the edges with bricks and configure firewood feed and combustion chamber (considering 5cm insulation). iv. Build up edges and combustion chamber (see the final outcome in Figure 3).v. Insulate combustion chamber. Banana stems as guides were used, but was later on removed rather than to leave them to get rotten in-situ.vi. Fill voids with compacted earth or bricks. vii.At appropriate height set the first (larger) pot in place and fill around it with insulation mix.See outcome in Figure 4.

Figure 3: Building edges and combustion chambers

Figure 4: Shape the size of the opening

viii. At the same height the channel to Pot 2 will be built with insulation mix, followed by pot 2 set into place. ix. Continue building up around the pots to desired height.x. Make a channel to the chimney and set up a form to build the pipe (banana stem works here too).See outcome in Figure 5. xi. Remove the pots and smooth all edges and surfaces inside, scraping down the surface around the pots to create hot air circulation. Place three clay supports to lift the pot- allowing heat to move under and around the pot. See outcome in Figure 6.

Figure 5: Stove depicting the chimney

Figure 6: Smoothened stove

Figure 7: Complete stove ready for use

Comparison of the proposed mud-brick and traditional wooden-cook-stove

There is a general lack of consensus about performance metrics of cook-stoves. Based on most literature, the units of certain output metrics are often unclear. For example, while grams of pollutant emitted per kilogram of wood combusted (g/kg) is a common and widely applicable emissions output metric, the data sources do not always specify whether the emission factor is gram per kg wet wood, dry wood, or dry wood equivalent, resulting in a significant lack of clarity and comparability (Berkeley Air Monitoring Group, 2012). In addition to the above challenges related to paucity of data, it is important to note that any comparative study should consider the type of pot used for cooking, characteristics and dimensions, type of food cooked, type of wood used, type of water and/or ingredient used in cooking. These are extremely challenging to obtain given the lack of standardisation of sources of these materials in Cameroon. However, given the exploratory nature of this study, we will report briefly on the differences (see Tables 1) between mud-brick and 3-stone fireside stove. The three criteria considered are technical, environmental and economic.

Table 1: Comparison of mud-brick and 3-stone fireside cook stoves

Technical			
	mud-brickcook-stove	3-stone fireside	Comments
Easy to find material to construct	yes	yes	
Ease to construct	With short training	yes	
Skills requirement	easy	none	
Ignition method	match	match	
Time to boil water			
Time to cook standard Bafut meal	Women report 1.5 hour for beans	No data available	Further experiments with other foods will be conducted.
Environmental			

Amount of wood used to cook a meal per household (it is important to state average family size)	3 pieces	6 pieces	Anecdotal (Further experiments will be conducted. The relationship between the number of wood and family sizes will be discussed)
Amount of kerosene used lighting	None except a little for ignition	None except a little for ignition	
Economic			
Capital cost	Labour	none	

As earlier discussed, this study is still in its preliminary stages. In the future more parameters especially with regards to environmental (e.g. amount of wood used per day per household (it is important to state average family size, Emissions (CO_2) generated), economic (e.g. average life span, cost payback time) will be investigated. The Better World Cameroon in Collaboration with ARPEDAC will conduct further investigations on the innovative mud-brick cook-stove recently built in some homes in Bafut using the modified version of the well-known Water Boiling Test (WBT) in ARPEDAC's laboratory in Yaoundé, Cameroon. The experimental rig is summarised in the Figure 8 below, and the following key parameters for performance evaluations will explored including, the kitchen indoor air quality (IAQ) checks, the flue gas analyser, logs ambient carbon monoxide (CO) and CO_2 levels. The results will then be compared with the conventional 3 stones fireside and other existing stoves in Bafut.

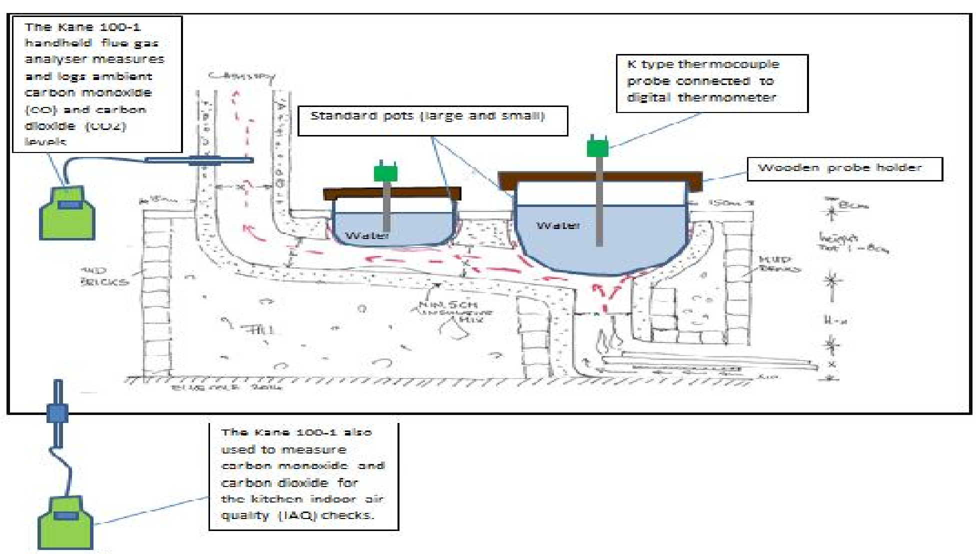


Figure 8: Testing Rig of the proposed mud-brick cook-stove

Conclusions and future studies

The aim of this study is to report on a recently mud-brick cook-stove designed for use in Bafut, a village located a few miles from Bamenda, the North-West regional capital of Cameroon. To achieve this aim, we investigated and discussed the design of a mud-brick cook stove. Furthermore, the initial performance of the mud-brick stove vis-à-vis some selected sustainability criteria and a comparison with traditional 3-stone fireside was examined. Although there was no significant difference between both (as indicated in Table 1), there are two major advantages of the mud-brick cook stove over 3-stone fireside. Firstly, the former offers great stability during cooking, as most households tend to use big pots as Figure 7. Secondly, smoke in the mud-brick cook stove is contained and controlled in such a way that it does not spread in the kitchen hindering visibility and blackening the walls. Thirdly, there is a potential of energy being conserved in the mud-brick cook stove than in the 3-stone fire side. As part of future studies, further experiments will need to be conducted to determine the performance of the proposed mud-brick cookstove. For example, the amount of heat conservedthe amount of CO_2 generated or conserved and the level of health impacts compared to other common stoves used in Cameroon.

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Solar Water Pasteurisation: Review and Potential

E. Ako, J. Kiplagat and I. Kiunga
Department of Energy Engineering, Kenyatta University, Box 43844, Nairobi.
Phone: +254 722863848, Email: ako.elias@ku.ac.ke

Key words: *Solar water pasteurization, Water disinfection, Drinking water, Solar water treatment*

ABSTRACT

This paper reviews pasteurization techniques and the potential for use of solar water pasteurization for treatment of contaminated drinking water. Access to safe and adequate water supply and improved sanitation is a fundamental need and a basic human right vital for health and dignity of all people. There are various techniques that have been used to disinfect water and make it safe to drink. These include: chlorination, ultra-violet disinfection, use of ozone gas, pasteurization and mixed-oxidant gaseous systems which is the most recent technology. Conventional water treatment methods rely heavily on chemicals, high energy consumption, use of expensive equipments and huge capital investments. Although they are suitable where large amount of water is required, they are not suitable for most rural settings existing in Kenya today that are normally scattered making centralized system a very expensive venture. Direct application of heat is one of the oldest and most reliable method of water disinfection. This review paper looks at the concept of heating water using solar thermal energy to kill disease causing organisms, mainly *E. coli* which is one of the major indicator of feacal pollution in water. The use of solar water pasteurization, would not only reduce the number of cases of water borne diseases such as cholera and typhoid which were identified as major cause of morbidity in Kenya by the Health Sub-sector Strategic Plan (1999-2004) but also lead to a reduction in environmental degradation, green-house gas emissions and health effects associated with inhaling smoke. It isn’t necessary to boil water to disinfect it, but can be heated to a pasteurizing temperature where it’s held for some time. Therefore water pasteurization using solar energy is a viable option for use in Kenya due to the abundance of solar energy resource.

1.0 INTRODUCTION

The most common and deadly pollutants in drinking water in developing countries are of biological origin and lead to many deaths due to waterborne diseases. In Kenya, 50% of the rural population and 25% of the urban population have no access to safe drinking water (National Development Plan, 2002-2008). Typhoid and Cholera (both waterborne diseases) have been identified as major causes of morbidity in Kenya due to environmental conditions related to lack of safe drinking water, hygiene and sanitation. Boiling of water before drinking is a safe practice for physical disinfection of water as it destroys micro-organisms.

Kenya lies between latitudes 5^{o}N and 4.5^{o}S of the equator and longitudes 34^{o}E to 43^{o}E of Greenwich meridian and has an average insolation of 700W/m^2 and mean daily sunshine duration of 7 hours. It is for this reason that solar energy utilization is feasible and a potential choice for water disinfection. Disinfection of drinking water is a process by which pathogenic organisms are destroyed or otherwise inactivated and can be accomplished by a number of physico-chemical treatments including direct application of thermal energy, UV radiation or addition of chemical reagents, e.g. chlorine. All these processes, though effective, have their own limitations emerging from technical, social and economic criteria. Effective microbiological purification of drinking water is an important consideration in the prevention and transmission of waterborne diseases.

Water quality studies have found that water from streams, ponds or open wells are likely to be contaminated with suspended organic and inorganic materials (Grandinetti, 1996). Microbiologically contaminated water places tremendous stress on health of many people especially in the rural areas and unplanned urban settlements which do not have treated water and therefore people drink directly from their respective sources without further treatment leading to frequent occurrences of diseases such as Cholera and Typhoid (Burris and Jorgensen, 2001). Microbiological quality of water is the most important aspect of water supply in developing countries since most of the rural population utilize surface water or open wells for drinking water. These surface water contain up to 1000 feacal coliform per deciliter of water as they are open to pollution from animal and human life (Feachem, 1980). Rural communities are scattered and therefore a central water supply system would be costly in terms of installation and operating costs. Disinfection using Ozone gas, UV and Mixed Oxidant Gas System are beyond the scope of rural communities because of high costs and technology associated with them.

Direct application of heat is one of the oldest and most certain method of water disinfection at household level (Classen, 2009; Sobsey, 2002). Biomass fuel is widely used to boil water for drinking over biomass-fuelled stoves in rural areas, this is because it is the only easily accessible fuel to the poorest population in developing countries. The depletion of this resource is of great concern due to the effects on the environment. Thus, with increasing global demand for energy, its increasing costs and depletion of non-renewable energy sources, solar energy has become a potential choice particularly in the rural areas as global focus on renewable energy continue to gather momentum.

2. DRINKING WATER CHALLENGES

Water intended for human consumption must be free from microorganisms that are causative agents of waterborne diseases. Most rural communities get their water from surface streams and much of it is contaminated by run-off carrying defecation and urination of human and livestock . There are about one million to a billion *E. coli* bacteria per gram of feaces (Metacalf, 1994). At any given time, about half of the population in the developing world suffers from one or more of the following disease associated with water supply and sanitation such as Cholera, Ascaris, Typhoid and Hookworm (UNICEF and WHO, 2009).

Over one billion people are exposed to unsafe drinking water due to poor quality of water source and lack of adequate water treatment. This results in 900 million cases of diarrhea each year (Rijal and Fujioka, 2001). The burden of diseases caused by contaminated water and lack of sanitation continues to be staggering particularly among young children in the developing countries and unsafe drinking water continues to be the major health challenges in the world today. Over 80% of all infectious disease in developing countries are transmitted through water and as a result more than two million children die each year (UNICEF, 2012). UNICEF (1989) estimated that 60% of rural families and 23% of urban families in developing countries are without safe water. UNDP (2003) reports that safe water remains inaccessible for about 1.1 billion people in the world and that the hourly toll from biological contamination of drinking water is 400 deaths of children below 5 years. More than 25,000 people die daily and more than 9 million annually due to diseases associated with contaminated water (UNCEF, 1989). The use of wood based fuels for water pasteurization and as the main source of energy for rural communities is a great source of concern as their depletion leads to serious potential consequences such as soil erosion, floods and desertification. It is therefore important to use alternative sources of energy, in particular solar energy.

3. MICROBIOLOGICAL PARAMETERS

The greatest danger to an individual health from water pollution is derived from pathogens, which are excreted in faeces and sometime in the urine of the disease carrier (both animals and human beings). Majority of waterborne diseases arise as a result of contamination of drinking water. Pathogens may be ingested directly by drinking or consuming food washed with contaminated water. Table 3.1 shows some common waterborne diseases and their causative pathogens.

Table 3.1 Common waterborne diseases and pathogens causing them

Disease	Causative organism
Cholera	***Vibrio cholerae***
Typhoid	***Salmonella typhi***
Paratyphoid	***Salmonella paratyphi***
Food poisoning	***Salmonella*** **species other than above**
Bacillary dysentry	***Shigella***
Dysentry	***Entamoeba histolytica***
Bilharzia	***Schistosoma***

Source: Tebbutt (1987)

The water industry has adopted the use of indicator species of bacteria to demonstrate that any contamination has taken place. The concentration of any indicator suggests the level of risk from associated pathogens. Although it is possible to examine water for specific pathogenic organisms, a much more sensitive test for routine analysis uses an indicator organism *Escherichia coli* that is a normal inhabitant of the mammalian gut. The presence of *E. coli* is an indicator of human or animal pollution and thus high possibility that pathogenic organisms are present.

The coliform group is widely accepted among water analyst as the best measure of faecal contamination. It is generally true that people in developing countries use surface or open wells for drinking water. These sources could contain more than 1000 faecal coliform per decilitre of water (Feachem, 1980). Recommended guidelines for bacteriological water quality according to WHO is that all water intended for drinking, no colform should be detectable in any 100ml sample taken with tolerance as follows: *E.coli* should not be detectable in any 100ml sample, no sample of 100ml should contain more than 3 coliform organisms; coliform organisms should not be detectable in any two consecutive samples of 100ml from the same or closely related sampling point (Tebbutt, 1987).

Table 3.2 and 3.3 show excretion rates of *E. coli* by eight species of animals and concentration of faecal bacteria in untreated domestic water source typical of developing countries, respectively.

Table 3.2. Excretion rates of *E.coli* by 8 species of animals

Animal Species	Feacal Production per day (grams)	Average *E.coli* per gram feaces	Daily Load of *E.coli*
Man	150.0	13.0×10^6	1.90×10^9
Cow	23,600.0	0.23×10^6	5.40×10^9
Hog	2,700.0	3.30×10^6	8.90×10^9
Sheep	1,130.0	16.0×10^6	18.10×10^9
Ducks	336.0	33.0×10^6	11.13×10^9
Turkeys	448.0	0.30×10^6	0.13×10^9

Chickens	182.0	1.30×10^6	0.24×10^9
Gulls	15.3	0.10×10^6	0.04×10^9

E. coli concentration $100ml^{-1}$ - Sewage – 3.4×10^5 – 2.8×10^7
Source: White and Godfrey (1985)

Table 3.3. Reported concentration of faecal bacteria in untreated domestic water sources

Source	Feacal Coliforms Organisms MPN/100ml of water *	Streptococci *MPN/100ml of waater*
Spring	0	0
Dams	0-2	0-14
Wells	11-350	50-90
Large rivers	10-100,000	10-10,000

* When a single value is given it is geometric mean. Source: Feachem (1980)

4. WATER DISINFECTION METHODS

4.1 Filtration

This is a process whereby water is purified by passing through a porous material or medium. It is a simple and effective technique for purifying surface water. Two types of filtration processes mainly used in water treatment are slow sand and rapid sand processes. Slow sand filtration is most commonly used and consists of layers of fine sand filter 0.6-0.9m thick BS no. 52 mesh (0.3mm) supported on layers of coarse gravel of BS no. 10 mesh (1.6mm). Perforated pipes at the base of the filter collects the filtered water and filtration rate is 0.1-0.3 $m^3/m^2/h$ so a very large surface area is required and is controlled by gravity alone.

Rapid sand filters utilizes a filter medium normally within the range of 0.5-1.5mm and have a filtration rate ranging between 5-10$m^3/m^2/h$ (about 50 times that of slow sand filters) and are mainly used for water that has been previously treated by coagulation or sedimentation. However the method is less effective than slow sand filters in retaining very small solids. Rapid sand filters have a higher loading rate and thus smaller and compact compared to slow sand filters. Both methods are expensive to operate.

4.2 Water pasteurisation

Boiling is the oldest method to obtain water free from biological contaminants. Biomass fuel is widely used to boil drinking water using biomass stoves. Biomass fuels are generally polluting and expensive when purchased (owing to low efficiency of cook stoves) but it is the only accessible fuel in developing countries. Holding water at 70°C for 6 minutes is sufficient to pasteurise the water and render it safe for human consumption (Feachman and Bradley, 1998). One way to provide clean drinking water is to heat-pasteurise it by heating the water to 65°C for 30 minutes or at 82°C for 15 seconds or an intermediate temperature for an intermediate time and it's not necessary to boil water (Andreatta, 2001). Since water can be disinfected by pasteurization at a much lower temperature than the boiling temperature (WHO, 2011), solar water pasteurization is considered one of the innovative water treatment techniques (Burch and Thomas, 1998).

The process of pasteurization and its use in milk is well known. Most milk is pasteurised at 71.7°C for 15 seconds or alternatively at 62.8°C for 30 minutes. Some bacteria are heat resistant and can survive in milk during pasteurisation, but these do not cause disease in people but however they spoil the milk, and hence pasteurised milk is kept refrigerated (Ciochetti and Metacalf, 1994). Franco *et al* (2007) also reported pasteurization of goat milk using a low cost solar concentrator (63°C for 30 minutes or 72°C for 15 seconds) kills or inactivates all vegetative *tubercle bacilli* (*Mycobacterium tuberculosis*). Some thermophyllic cells survive up to 80^{o}C and boiling kills all vegetative microorganisms in 10 minutes (Ciochetti and Metacalf, 1994).

Koottatep (1988) performed an experiment to disinfect water using 2 types of flat plate collectors, with glass tubes and copper tubes respectively. A temperature range of 51^{o}C-60^{o}C was achieved using glass tube collector with 50-67% inactivation of coliform present. Higher temperatures above 60^{o}C were attained using the copper tube collector ensuring 100% feacal coliform inactivation of natural water. It was also established that at below 50^{o}C, only 16% of the faecal coliforms could be inactivated. Retention time of 15 and 20 minutes ensured complete disinfection in copper and glass tubes respectively.

Andreatta (1994, 2001), developed a water pasteurisation indicator (WAPI) which is a polycarbonate tube, sealed at both ends and partially filled with blue Soya bean fat that melts at 69^{o}C.

4.3 Solar water treatment devices

Accra *et al.* (1984) established that exposure of drinking water for a few hours of sunshine in a transparent material reduced the amount of coliform bacteria in water. It was established that 99.9% of coliform bacteria were killed by sunlight in 95 minutes compared to 630 minutes under normal room conditions. Investigations into possible re-growth of the bacteria showed that inactivated coliform bacteria failed to re-grow after 5 days under ordinary room conditions hence disinfected water through solar radiation may safely be stored in the home provided the water does not get re-contaminated.

4.3.1 Solar box cooker

This is the simplest solar water purification device and is well known for cooking food. It can also be used for water pasteurization. A covered pot is placed inside the box where it remains until the water reaches 65^{o}C for some minutes. It can pasteurize 4-12 litres per day and thus only suitable for small families. Its cost is of the order US$20 (Solar Box Cookers, 1998).

4.3.2 Flow through pasteurization devices

In order to produce more water, PAX world service produced a flow through unit consisting of 15m of black tubing coiled within a standard solar box cooker. One end of the tubing is connected to a thermostatic valve and the other end to a storage tank containing pre-filtering material. Small amount of water within the tubing allows rapid heating of the water to valve opening temperature of 83.5^{o} C. As the pasteurized water drains, contaminated water from the storage tank automatically refills the tubing. It yields 16-24 litres a day and the cost is of the order US$150. Four to five times water output was achieved over a flow through unit with a heat exchanger and a solar powered water pump corresponding to 80-96 litres of treated water per day. The cost of this system is about US$270 (Metcalf, 1994).

4.3.3 Parabolic trough pasteuriser

This device was developed by Florida Solar Energy Centre and uses a parabolic trough concentrator on copper pipes placed across the centre of the trough. The copper pipes use heat exchanger principle with 3 nested pipes that create an outer and inner channel. Untreated water is pumped into the outer channel where it is heated directly by the concentrated solar radiation. After the water reaches the end of the pipe, it returns through the middle and preheats the untreated water. It uses standard automotive thermostatic valve with a PV panel supplying electricity for the pump, and produces

2500 litres of drinking water per day using 28m^2 concentration area. The price of the system is beyond means of rural communities in developing countries (Anderson, 1996).

4.3.4 Solar PV Pasteuriser

Conventional technology also can treat water in remote areas, by combining PV cells that produce electricity with compact, sturdy equipment for UV light disinfection and may be preferred where chlorination is unavailable or unwanted. Gadgil and Shown (1995) produced a UV system for field use. This system provided water for a large village with UV light running on electricity. The system makes use of both filtration and UV light for disinfection with a 2m^2 PV panels or a 12V car battery providing electricity. PV cells can also provide power for mixed-oxidant disinfection system. These systems use sodium chloride (table salt) to produce a highly active oxidant mixture. Venczel and Sobsey (1997) examined the effectiveness of this system in the laboratory and in a village in Bolivia and concluded that on-site production of mixed-oxidant disinfectants can provide inexpensive and effective disinfection where conventional treatment and distribution are unavailable. The disadvantages of this system are the pressurized raw water required for its operation, the high installation costs and the requirement of a highly skilled labour force.

4.3.5 The Solar Puddle

This is a low cost large area device and is essentially a puddle in a greenhouse and is a useful pasteurizer where water delivered per unit cost is an important figure of merit. A shallow pit about 1m^2 by 0.1m deep is dug and insulated with native materials (paper, straw, grass or leaves). Over these are layers of clear and then black plastic with edges extending out and over the sides of the pit. A drain siphon is installed in the lowest part of the trough and weighted down with rocks. Water is added to a depth of 0.025m to 0.075m. A layer of clear plastic is laid over the water with edges extending over the edges of the pit. Spacers are placed on this plastic layer and a final layer of plastic placed on top of the spacers which should be at least 0.05m apart. Water needs to be added on each day. On a sunny day the device produces about 70 litres of water a day and the cost is of the order US$40 (Andreatta, 2007).

4.3.6 The Solar still

A solar still usually consists of a large flat surface mounted on legs. A short wall is built around the top of the table and lined with impermeable material (ideally black, high-temperature silicone rubber) to make a small pool of water on the top of the table. A pane of glass is mounted at slight angle above the table. As the water is heated, it forms vapour which condenses on the pane. Gravity pulls the condensate to the lower edge of the pane, which overhangs the pool, and drips into a trough, and then through a hose or a tube into a collection jug. On a clear day a still of 1m by 2m produces about 12liters of water a day. The major drawbacks of solar still technology is that it is viable only for the production of relatively small quantities of fresh water about 2-3 litres/m^2/day and requires large areas of land because of the low productivity. Solar stills are considered more economical in the case of seawater desalination.

5.0 CONCLUSION

Solar water pasteurizers are feasible application for provision of safe drinking water from a dubious quality water source and is effective in inactivating disease causing bacteria and does not require an additional input of external energy. It isn't necessary to boil water to disinfect it, but can be heated to a pasteurizing temperature where it's held for some time. Therefore water pasteurization using solar energy is a viable option for use in Kenya. More over, Kenya receives an average insolation of 700W/m^2 and over 80% of the population live in rural areas. Most people live in scattered rural settings that make a central water supply expensive.

The following strategies can be adopted in developing a solar water pasteurization system for rural community use in Kenya:

1. Use of locally available material as much as possible for the construction of the solar water pasteurizer. Consideration in the selection of the materials also included low cost, easy handling during fabrication and ability to withstand local environmental and operating conditions.
2. Improvement on the flow through pasteurization device and to incorporate a parabolic concentrator with mirror reflector to enhance the performance by increasing the concentration of solar radiation incident on the absorber surface of the collector with the overall objective of increasing the pasteurized water output at much lower costs.
3. Use of thermostatic valve to regulate the pasteurization discharge temperature as the use of water pasteurization indicator (WAPI) is not practical in the case of self discharge of pasteurized water.

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Renewable energy policies and practices in Kenya and their contribution to appropriate technology adoption

Christine W. Njiru[1*], Sammy C. Letema[1], Simon M. Maingi[2], Patrick M. Gichohi[3]
[1]Environmental Planning and Management Department, Kenyatta University, P.O Box 43844-00100, Nairobi, Kenya
[2]Water and Environmental Engineering Department, Kenyatta University, P.O Box 43844-00100, Nairobi, Kenya
[3]Zoology Department, Jomo Kenyatta University, P.O Box 62000-00100, Nairobi, Kenya.

*Corresponding author. Cell phone 254722400931, E-mail christine.njiru26.cn@gmail.com

Abstract
Kenya is facing challenges in energy provision with majority of rural populations experiencing energy poverty exhibited by lack of access to electricity and reliance on traditional fuels for cooking. The main purpose of this paper, therefore, is to examine renewable energy policies and practices in Kenya and their contribution to appropriate technology adoption. The study undertook content analysis of project reports and policy documents. Results show that demand for electricity in Kenya is 7% per annum over the past 10 years. Consequently, electricity access has risen from 12% in 2004 to 35% 2012 of the total population but a large proportion of population is located far away from the national grid where it is uneconomical to connect to the grid. Kenya has drafted renewable energy policies in a bid to shift dependence from hydropower which is affected by weather patterns and petroleum affected by price fluctuations to solar, wind and geothermal which are renewable. However, the adoption rate of renewable energy technologies is low due to financial constraints, lack of awareness and lack of coordination between the government, non-governmental organizations and private sector players. Existing renewable energy policies should be harmonized while current practices should be evaluated in order to up scale the adoption rate of the renewable technologies.
Keywords: Kenya, energy poverty, renewable energy, policies, practices.

1. Introduction

Energy is an essential component in the development of any nation. Between 2005 and 2030 the world energy demand is expected to grow at an average annual rate of 1.8%, with 20 major economies contributing to 84% of the increase (Lee, 2013). The increased demand in global energy can be attributed to energy being a major player in wealth generation and driver for socio-economic development (Akpinar *et al*., 2012; Koskimaki, 2012).

Africa is full of energy resources but harnesses only a little of these for domestic consumption while renewable energy resources mainly hydropower, geothermal and wind are abundant (IEA, 2012). Africa also has the lowest electrification rates in the developing world (Dasappa, 2011), with the number of people without electricity expected to rise in sub-Saharan Africa (SSA) (Owen *et al.*, 2013). Power utilities in Africa have failed to provide adequate levels of electricity services especially to the rural and urban poor (Karekezi and Kimani, 2002). In sub-Saharan Africa, 70-90% of primary energy supply and up to 95% of total energy consumption is from traditional biomass energy (Karekezi 2002). Despite efforts to promote electrification in sub-Saharan Africa, the region has the lowest electrification rates with more than 650 million people relying on traditional biomass for cooking and heating (Lins, 2012). These areas offer impetus for decentralized renewable energy technologies that better match the dispersed nature of settlements and are also environmentally sound (Dasappa, 2011; Pirlogea and Cicea, 2012; Dermibas, 2009). However, information of such decentralized renewable energy technologies is often scanty, thus focus of this paper to fill the gap.

2. Kenya’s Energy Profile

2.1 Energy consumption

Kenya’s energy profile is dominated by traditional biomass to meet energy needs of rural households and a heavy dependence on imported petroleum for the modern sector. The other renewable energy sources mainly solar, wind power and biogas contribute a small fraction of energy sources (Onuonga, 2012). The rural electrification rate was 2.0% in 2002 (Karekezi, 2002) and rose slightly to 4.0% in 2011 (Lins, 2012). The number of people relying on traditional biomass for cooking is 83% of the population (Lins, 2012). This is because majority of the population is rural and because they are poor, they cannot afford modern energy sources e. g. electricity and even for the few who can afford, it is not readily available (Karekezi and Kimani, 2002) and electrification of the poor is not given priority (Nyoike, 2002). Consequently, the country faces challenges related to unsustainable use of firewood and charcoal and exposure to high and unstable oil import prices (UNEP, 2010). Notably, the rural households willing to use the modern services are discouraged by the high costs of connection (Abdullah and Markandya, 2011).

2.2 Electricity access and generation capacity

Demand for new electricity connections has been rising. In 2004 the government started subsidizing new electricity connections by charging Ksh. 34, 980 (single phase) and 49, 080 (three phase). The new connections increased the number of customers from 735,000 to over 2 million effectively raising electricity access from 12% (2004) to 35% (2012) of the total population (Kenya Power, 2013). In the 2012/13 year, there were 292,337 new customers raising the customer base to 2 330 962 (Chumo, 2013). However, our energy sector still lags behind that of middle income countries and is in line with low income and SSA averages (KIPPRA, 2010). Renewable energy technologies (RETs) will be a viable option because they can easily be decentralized thus providing energy in areas far from the national grid.

According to the Ministry of Energy (MoE) (2013a) the effective power generation capacity in Kenya is 1664 MW with a shortfall of 536 MW. The government has come up with a programme aiming to raise generation capacity by 5000 MW. This will be attained through government power utilities and independent power producers (MoE, 2013b). Once the programme is implemented, electricity generation cost is expected to reduce from 11.30 to 7.41for commercial tariff, industrial tariff from 14.14 to 9.00 and domestic tariff from 19.78 to 10.45 US$ cents (MoE, 2013a). Reduction in price of energy will stimulate economic activities especially in rural areas when they access the modern energy services.

Kenya’s electricity generation mix is dominated by hydropower comprising 50 % of the existing capacity and is thus vulnerable to weather conditions (Kenya, 2013a). The climatic conditions of 1998-2000 and 2008-2009 led to a decline in hydropower production. This led to severe energy shortages that culminated in power rationing, an experience that made the government to appreciate the linkages between energy, environment and the country’s socio-economic development (Kenya, 2011a). This prompted the government to shift focus to exploitation of other renewable energy sources, mainly geothermal, solar, wind and biogas, which are not mainly weather dependent. This paper therefore aims to evaluate how renewable energy policies have informed the energy practices in the country in a bid to overcome the challenges. Focus is on renewable energy policies and practices because RETs can help Kenya meet her energy needs while taking care of the environment.

3. Renewable Energy Policies and Practices

The government intends to develop these renewable energy sources in order to minimize production cost and make electricity affordable to the majority of Kenyans. Kenya has continually reviewed its renewable energy policies in a bid to address the rising demand for energy. They are contained in various Sessional Papers and Acts **(**Table 1).

3.1 Wood-fuel practices

Since the 1980's, the government has issued bans on production and transportation of charcoal to curb illegal deforestation but enforcement is not firm because of corruption by enforcing authorities (GVEP, 2010). Delays in issuance of licenses for sustainable charcoal production allow illegal charcoal to dominate the market while brokers exploit producers thus discouraging sustainable supply (Liyama, *et al*., 2014).

3.2 Biogas practices

A number of pilot and small commercial biogas projects for heat and electricity generation are in operation. Biopower Limited in Kilifi County generates 150 kW from a mixture of sisal and cow dung, banana leaves in Kamahuha in Murang'a County generate 10 kW; whereas Agro-Chemical and Food Company's bulk volume fermenter at Muhoroni generates 23,000 m^3 of gas per day from the distillery effluent (Kenya, 2013b). The MoE also initiated pilot projects for electricity generation from cut flower waste in Kiambu and Kajiado (Kenya, 2013b). The projects indicate potential for power generation from floriculture waste, which flower farms can utilize and be self sufficient in their power needs (Gichohi, 2014).

3.3 Cogeneration energy practices

Potential exists for co-generation using bagasse in sugar factories in Kenya (Kiplagat *et al.,* 2011). However, only Mumias self sufficiently generates its power needs, 38 MW, and exports the surplus which is 26 MW to the national grid (Kenya, 2013b). Cummins Cogeneration Kenya Limited is building a 12 MW biomass plant at Marigat in Baringo County, which will use mesquite wood from *Prosopis juliflora* (Senelwa, 2014). Thus co-generation activities are not well developed in Kenya.

3.4 Solar energy practices

Kenya government has been providing lighting and water pumping photovoltaic installations to public institutions and public water wells in arid and semi-arid lands where there is no access to the national grid (Kenya 2011a). By 2012, 945 institutions had benefited from the program. The government has installed solar/wind hybrid generators to off-grid stations in different parts of the country (Kenya, 2013b). These practices demonstrate the government's commitment to promote solar energy.

Table 1: Renewable energy policies and practices in Kenya

Policy	Provisions	Reference	Practices	Reference
Sessional Paper No. 6 of 1999 on Environment and Development	• Develop comprehensive energy policy • EIA is a requirement for all energy projects • Promote adoption of energy efficient technologies	Kenya, 1999a	• Drafting of National Energy Policy 2013 • EIA carried out for all energy projects • Signing of Energy Efficiency Accord	Kenya, 2013b CCPS, 2013
Environmental Management and Coordination Act, 1999	• Creation of NEMA charged with promotion of renewable energy sources	Kenya, 1999b	• Energy projects undertake EIA before commencing.	Kurrent Technologies Ltd., 2012 Muthuri, *et al.* 2009
National Environmental Policy, 2012	Requires energy projects be environment friendly	Kenya, 2012	EIA carried out on all energy projects.	
Water Act, 2002	Deals with all matters relating to water usage and pollution control.	Kenya, 2002	Creation of Water Resources Management Authority which licenses water use for energy projects.	Kenya, 2002
Sessional Paper No. 4 on Energy of 2004	Outlines national policies and strategies for the energy sector. Recognizes need to integrate energy planning with the national economic, social and environmental policies.	Kenya, 2004	Enactment of Energy Act 2006 to guide implementation of policies in Sessional paper No.4 on Energy.	Kenya, 2004
The Energy Act, 2006	Creation of institutions and legal framework to manage energy sector and promote development and use of RETs.	Kenya, 2006	Unbudling of Kenya Power and Lighting Company into Geothermal Development Company, Kenya Electricity Transmission Company	Kenya, 2011b MoE, 2013a

			Ltd, Kenya Electricity Generating Company, Rural Electrification Authority, Kenya Nuclear Electricity Board and allowing IPP in the energy sector. Promotion of Kenya Ceramic Jiko	Kiplagat, *et al*., 2011.
Feed-in- Tariff Policy, 2010	Instrument to promote generation of electricity from renewable energy sources.	Kenya, 2010	Mumias Sugar Company practices cogeneration. Imenti Tea Factory has small hydropower project.	Kenya, 2013b UNIDO and ICSHP, 2013
Sessional Paper No. 9 The Forest Policy, 2005	Aims to empower local communities to manage forests through Community Forest Associations (CFA).	Kenya, 2005	CFAs formed in major catchments and they are involved in conservation of forest resources.	
The Forest Act, 2007	Deals with protection and sustainable management of forest resources.	Kenya, 2007	Kenya Forest Service licences charcoal production. Briquette making enterprises.	Liyama, *et al.*, 2014 GVEP, 2010

Source: Compiled by author based on references given in the Table. Key: EIA Environmental Impact Assessment; CFAs Community Forest Associations; UNIDO United Nations Industrial Development Organization; RETs Renewable Energy Technologies; GVEP Global Village Energy Partnership-International; CCPS Center for Cooperation with the Private Sector; NEMA National Environment Management Authority; ICSHP International Center on Small Hydro Power; KTDA Kenya Tea Development Authority.

3.5 Wind energy practices

Kenya has little experience with wind power generation but there is increased awareness and interest in the sector (Kiplagat *et al*., 2011). There is only one wind farm operated by KenGen at Ngong Hills in Kajiado with a capacity of 5.1 MW (Kenya, 2011a). The government has approved several applications to exploit wind power. These include, Ngong Phase II (13.6 MW), Ngong I Phase II (6.8 MW), Lake Turkana Wind Power (300 MW), Aeolus (60 MW), Prunus (50 MW) and Kipeto (100 MW) (Kenya, 2013b).

3.6 Bio-fuel practices

The MoE enacted the ethanol blending regulations to produce biodiesel (MoE, 2010). The government has provided 500,000 acres of land for *Jatropha curcas* cultivation (Kiplagat *et al.*, 2011) but commercial extraction of biodiesel for blending has not commenced (Kenya, 2013b). More effort is needed to upscale contribution of biofuels to the energy mix.

3.7 Small hydropower practices

Kenya Tea Development Authority has invested in construction of mini hydro plants with a total capacity of 22 MW while there are 19 documented operational small hydropower projects in Kenya (UNIDO and ICSHP, 2013). Implementation of these projects started before independence but uptake has been slow indicating that the FiT policy has not encouraged uptake of the technology

4. Conclusion

Kenya has great potential of renewable energy sources that supply more than 50% of the electricity. Focus has been on large hydropower projects and lately geothermal power while biomass, solar, biogas, and wind are under exploited. There is need to harmonize all policies affecting renewable energy exploitation in order to ensure timely implementation of the planned projects. Existing policies should also be reviewed regularly to encourage private investment in the sector and also ensure competiveness within the sector. Renewable energy practices are in line with existing policies. However, adoption of renewable energy technologies has been slow mainly because most of them require high upfront costs. Subsidies for biogas technology have improved the uptake rate while feed-in-tariffs have encouraged public-private partnerships in implementing geothermal and wind energy projects. More focus should be towards improving financial incentives to encourage investment in the energy sector.

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Characterisation and Rate of Biogas Production of Selected Mixtures of Livestock Droppings

[1]Peter M. Ndungu: Phone: +254 723570848: Email: muirupeter13@yahoo.com
[2]Godfrey M. N. Ngunjiri: Phone: +254 722504936: Email: gmnngunjiri@gmail.com
[2]Daudi M. Nyaanga: Phone: +254 721285 231: Email: dmnyaanga@gmail.com
[2]Raphael M. Wambua: Phone: +254 723797872: Email: wambuarm@gmail.com

[1]Department of Industrial & Energy Engineering, Egerton University, Kenya
Egerton University, P.O. Box 536-20115, Egerton, Kenya
[2]Department of Agricultural Engineering, Egerton University, Kenya

ABSTACT

A research was conducted at Agricultural Technology Development Centre Nakuru, Kenya, to study the rate of biogas production of selected Livestock dropping mixture ratios. Eleven 20-litre digesters were used to compare biogas production from mixtures of cow dung and chicken droppings (CC) and cow dung and sheep droppings (CS) at ratios of 1:0, 9:1, 7:3, 1:1, 3:7, and 1:9 each. Total and volatile solids and their respective slurry densities of the mixtures were determined before and after they were introduced into the digesters. The mean influent percent total solids (TS) for the ratios (9:1, 7:3, 1:1, 3:7 and 1:9) of CC and CS were respectively 9.70% and 10.52%. That of CA (1:0) was 9.52%. The corresponding total solids for CC and CS effluents were 7.71% and 8.55%; while that of CA was 9.09%. These values were within what is appropriate for biogas production. Biogas production for CC and CS were 0.41m^3/day and 0.38m^3/day respectively. Both of these values were significantly different at $\alpha \leq 0.05$ from that of CA, which was 0.22m^3/day. It was concluded that mixing cow dung with chicken and sheep droppings improved the rate of biogas production.

Key words: Livestock droppings, substrate, total and volatile solids, rate of biogas production

1. INTRODUCTION

Potential of biogas plants as a source of both energy and fertilizer has been recognized by several authors: Fulford, 2001; FAO, 1992; Legget, et al., 2006; FARMESA, 196; Muturi and Mbuthi, 1999. Fitzgibbon et al., 2005, noted that anaerobic digestion is widely accepted as a sound technology for waste treatment. Bio-digesters can be fed with animal and human waste. Biogas plants help to reduce the population of insects like flies and mosquitoes BIOFRAC, 2006, resulting in a healthier environment. Cheruiyot *et al*., (2009), studied the behaviour and performance of plastic biogas digesters using cow dung under natural and greenhouse conditions and suggested further studies on a variety of substrates such as chicken waste, pig waste, sheep and goat droppings or combinations of these.

Most Kenyan rural small scale farms practice mixed farming with one or two dairy cows, some chicken and more often than not, some sheep and/or goats. Hence, the need for the study to establish the potential for biogas production for these mixtures, in order to assist the rural small scale farm holders to generate biogas for their domestic use. This would go a long way in reducing their dependency on firewood for cooking; and paraffin for lighting, thereby reducing deforestation and environmental pollution. Despite the abundance of raw material and benefits for biogas technology, rate of adoption for biogas technology is low. Studies by Jecinta, 2008 on technological constraints to adoption and sustainability of biogas technology reported only 1.6% adoption rate in Nakuru County. Studies by Ngunjiri et al., 2014 observed that, different mixture ratios of cow dung and chicken droppings; and cow dung and sheep droppings generated biogas. The study however did not include the amounts of biogas generated by the different slurry mixtures. Hence the need for this study to analyse the rate of biogas production by selected livestock waste mixtures.

2.0. MATERIAL AND METHODS

The research was carried out at the Agricultural Technology Development Centre, Nakuru, Kenya. Experimental digesters consisted of 11 units which served to produce gas from the substrate mixtures. The basic set up consisted of a 20 liter jerrican, 5 liter displacement bottle and a measuring conical flask all connected through rubber and capillary tubes. At the top of the experimental digester a plastic cork with a well fitting capillary tube was used to close the outlet. The lid was then sealed using reinforced plastic resin. The well fitting plastic and capillary tubes were used to connect the digester via a release valve to the 5 liter displacement bottle filled with water to capacity. Figure 1 show a schematic diagramme of the general experimental set up.

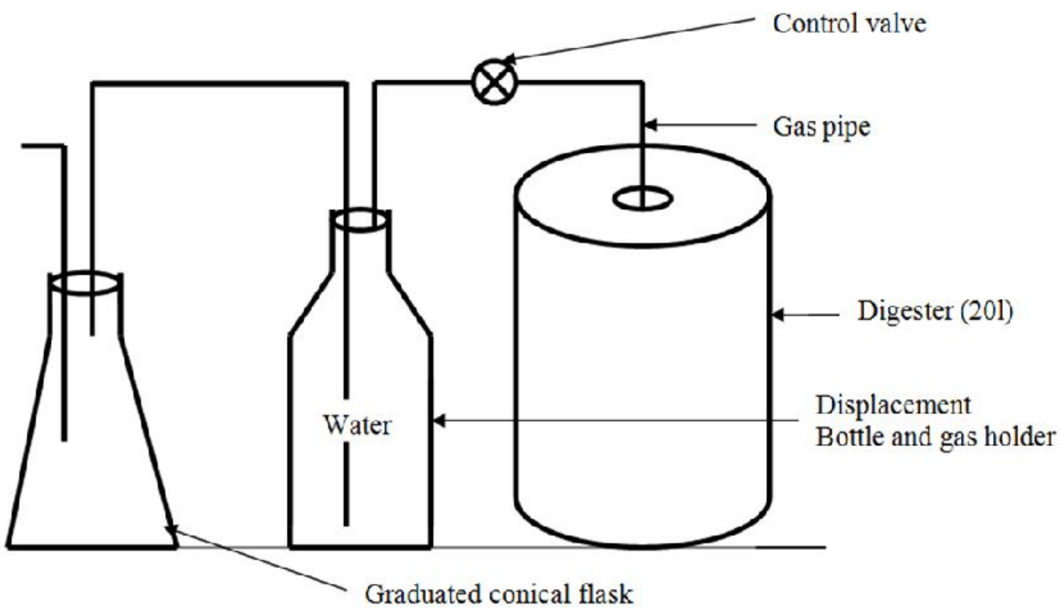

Figure 1: Schematic representation of experimental set up

2.1. Determination of Total Solids

A sample of the slurry was transferred into a pre-weighed dish and then weighed. The dish plus its contents were placed in an oven set at $105^{o}C$ for 12 hours. Thereafter, the dish and its content were removed and allowed to cool to room temperature ensuring that the dried sample does not re-absorb moisture from the atmosphere before it was weighed. After the dry sample attained room temperature, it was removed and immediately weighed as shown in Figure 2. The proportion of the total solids in the sample is given by the weight of the dried sample divided by the weight of the original wet sample as shown in Equation (1).

$$TS = \left(\frac{x - b}{w - b} \right) \times 100\% \qquad (1)$$

Where;

TS = Total solids (%)
X = Weight of dish + dry sample (g).
W = Weight of dish + wet sample (g).
b = Weight of empty dish (g)

2.2. Determination of Volatile Solids

Volatile solids (VS) are the organic solids lost when the dry matter is incinerated at 550^{o}C. A weighed sample of each mix ratio was transferred into a crucible dish and placed into a muffle furnace set at 550^{o}C for four hours. Thereafter, samples were removed and taken to a desiccator and left to cool to room temperature. After cooling, the crucible dishes with their contents were removed and new weights taken. The volatile solids proportion is the difference between the weight of the dried sample

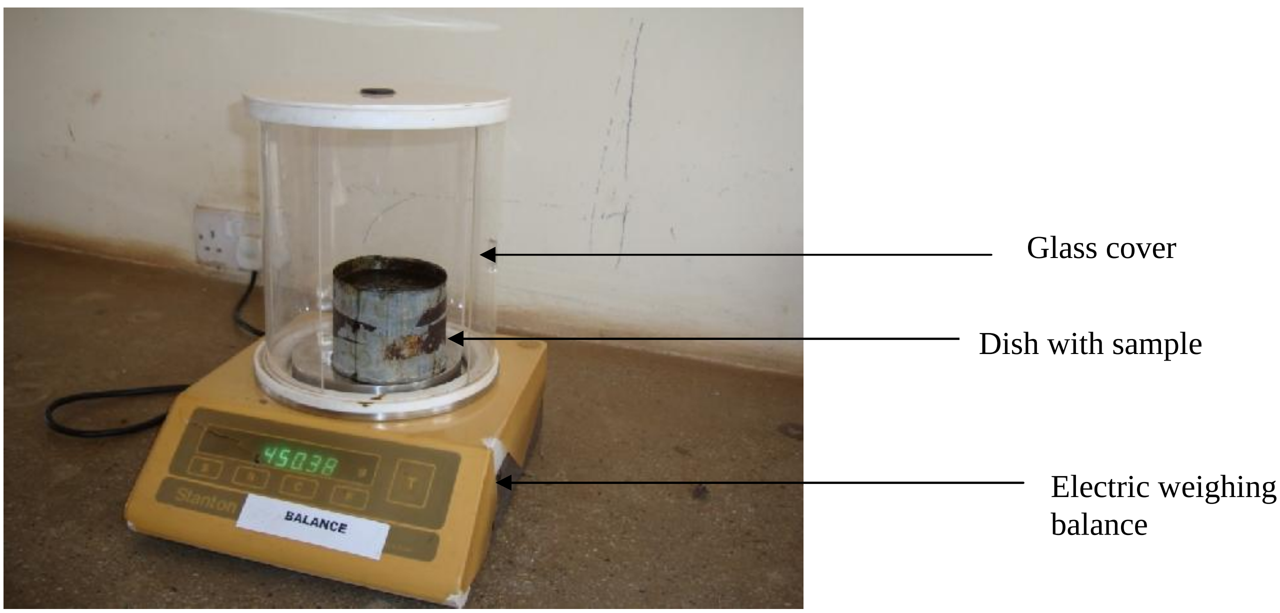

Figure 2: Measurement of total solids.

before and after combustion, divided by its weight before incineration as illustrated in Equation (2).

$$VS = \left(\frac{(N - m) - (Z - m)}{(N - m)} \right) \times 100\% \qquad (2)$$

Where;

VS=Volatile solids (%)
N = Weight of dish + dried sample
Z= Weight of dish + weight of ash
m= Weight of dish.

The procedure was repeated three times.

2.3. Rate of Biogas Generation

The gas yield was measured daily using the displacement method. A 5-liter plastic bottle was filled with water to capacity and connected to a graduated conical flask for each treatment (digester). The pressure of the gas from the digester forced water to flow from the plastic bottle into the conical flask which was graduated in milliliters. A valve placed in between the digester and the displacement bottle was open for gas measurement at a specific time and closed after all the gas for each day was exhausted. The volume of water displaced represented the volume of gas generated in one day for each treatment, Figure 3.

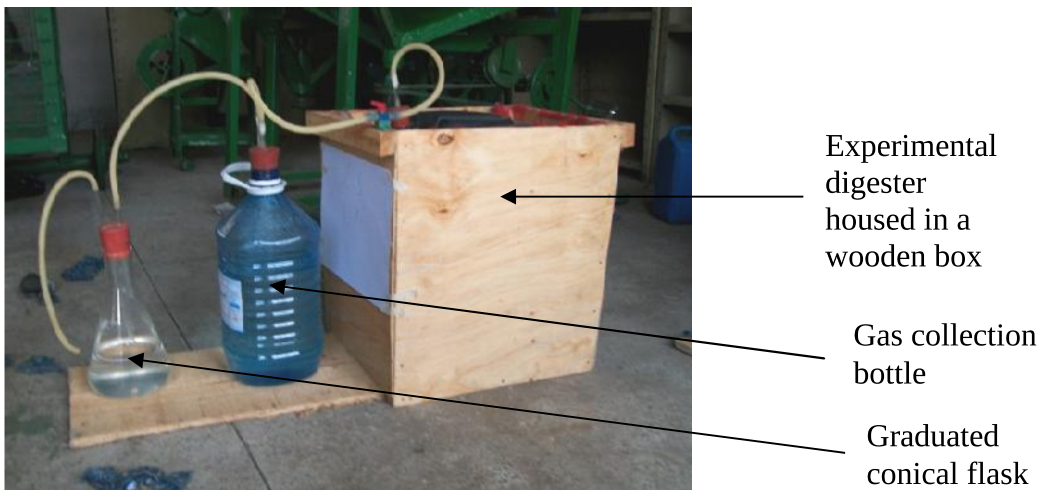

Figure 3: Experimental set up showing gas collection system

3.0. Results and Discussions.

3.1. Total solids

Dry matter (DM) content of pure chicken and sheep droppings were found to be 15.78% and 27.78% respectively, while the recommended value for biogas digester slurry is between 8 to 12%. Thus, the droppings were diluted with water to the required consistency before being introduced into the digester. Table 1 shows the percent total and volatile solids, (TS & VS) of substrate mix ratios for both influent and effluent. The percentage total solids for the influent varied from 8.57 to 11.40% for CC while that of for CA was 9.52%. The ratio 9:1 had the highest value of 11.40%, which was significantly higher than those of CA and other ratios at the 0.05 level of significance. However, the dry matter contents for all the mixture ratios were within what is recommended for biogas digesters. The effluent total solids varied from 7.14 to 8.52% for the substrate mixtures and that of CA was 9.09%.

Table 1: Percent Total and volatile solids means of substrates for influent and effluent

Ratio	CC				CS			
	Influent		Effluent		Influent		Effluent	
	TS	VS	TS	VS	TS	VS	TS	VS
1:0	9.52^{b}	7.45^{a}	9.09^{a}	6.18^{ba}	9.52^{ba}	7.44^{a}	9.09^{b}	6.18^{ba}
9:1	11.40^{a}	8.95^{a}	8.52^{ba}	5.81^{ba}	9.01^{b}	7.14^{a}	7.50^{b}	5.24^{a}

7:3	9.65^{b}	7.74_{a}	7.42^{ba}	5.11^{ba}	10.40^{ba}	8.23^{a}	7.78^{b}	5.26^{ba}
1:1	9.27^{b}	7.26^{a}	7.14^{b}	4.78^{b}	10.36^{ba}	8.00^{a}	8.33^{b}	5.63^{ba}
3:7	8.57^{b}	6.54^{a}	7.65^{ba}	5.09^{b}	11.21^{ba}	8.73^{a}	8.55^{b}	5.75^{b}
1:9	9.41^{b}	7.58^{a}	7.81^{ba}	5.55^{a}	11.25^{a}	8.81^{a}	10.61^{a}	7.00^{b}

Means followed by the same letter(s) in the same column are not significantly different at α = 0.05

The ratio 1:1 had the lowest effluent total solids of 7.14, which was significantly different with that of CA but not with other mixture ratios.

Total solids concentration for CS influent varied from 9.01% to 11.25%, and was 9.52% for CA. The ratio 1:9 had the highest value of 11.25% although it was not significantly different with that of CA. The other ratios were the same except the ratio 9:1 which had the lowest value of 9.01%.

The values for effluent total solids for CS varied from 7.50 to 10.61%. These values were not significantly different with that of CA except the ratio 1:9 with a value of 10.61 which was significantly higher than that of CA.

Generally, the values of effluent total solids show a consistent drop in every ratio in comparison with the influent. This suggests a healthy metabolic activity involved in formation of methane having taken place. Some substrates indicated a higher drop in total solids from influent to effluent than others. This may be due to active ingredients involved in combining the two substrates which may have, enhanced or otherwise, the digestion process. This is also reported by [20], who states that the total solids vary from substrate to substrate due to different degradable speeds.

3.2. Volatile solids

Results of the volatile solids for both influent and effluents are shown in Table 1. Percent volatile solids for the CC influent varied from 6.54 to 8.95 and that of CA was 7.45%. These values were not significantly different at α = 0.05. The values for the effluent volatile solids varied from 4.78% to 5.81% and that of CA was 6.18%. The CC mixture ratios of 1:9, 1:1 and 3:7 were significantly different with that of CA, while the remaining ratios were the same.

The influent percentage volatile solids for CS varied from 7.14% for the 9:1 ratio to 8.81% for the 1:9 ratio, while that of cow dung alone was 7.45% as stated earlier. These values were not significantly different. Volatile solids for the CS effluent of the substrate mixtures varied from 5.24 to 7.00%, while that of CA was 6.18%. These values were also not significantly different except for the ratios 9:1, 3:7 and 1:9, which were significantly lower than for the other mixture ratios. The results show that increasing concentration of chicken or sheep droppings in the influent for the ratios did not affect the volatile solids significantly.

3.3. Gas Production

The weekly daily means gas produced by the mixture ratios for CC droppings, CS and CA are shown in Table 2. They ranged from 236 to 1,104 ml/day, 243 to 814ml/day for CC and CS respectively and that of CA ranged from 202 to 398ml/day. From the table, it is evident that weekly gas production was highest and significantly different ($\alpha < 0.05$) on the 3rd week for all mixture ratios.

The results also indicate a general increase in total gas produced by the mixture ratios in comparison with CA. This shows that mixing of the substrates improved the population of bacteria and growth conditions.

The cumulative total means of gas produced for the entire hydraulic retention period (28 days) for each mixture ratio are presented in Table 3.

Table 2: Weekly daily mean gas production (ml/day) of the different mixture ratios

Week	Ratio										
	9:1		7:3		5:5		3:7		1:9		1:0
	CC	CS	CC	CS	CC	CS	CC	CS	CC	CS	CA
1	0^{d}	0^{d}	0^{d}	0^{d}	0^{d}	0^{d}	0^{d}	0^{d}	0^{d}	0^{d}	0^{d}
2	324^{c}	352^{b}	761^{b}	403^{c}	240^{c}	254^{b}	304^{b}	243^{b}	615^{a}	403^{c}	202^{b}
3	6 12^{a}	438^{a}	1,104^{a}	814^{a}	653^{a}	483^{a}	496^{a}	586^{a}	399^{b}	637^{a}	398^{a}
4	433^{b}	448^{a}	574^{c}	505^{b}	409^{b}	491^{a}	581^{a}	571^{a}	236^{c}	590^{b}	267^{b}
Lsd	96	30	96	30	96	30	96	30	96	30	30

Means followed by the same letter in the same column are not significantly different at $\alpha < 0.05$.

Table 3: Total mean gas production (m^{3}) per retention time (28days)

Mixtures	Ratios						
	9:1	7:3	5:5	3:7	1:9	Mean	1:0
CC	10.37	17.0	9.52	11.54	9.556		6.04
Daily Mean (m^3/day)	0.37	0.61	0.34	0.41	0.34	0.40	0.22
CS	8.52	13.29	8.85	9.87	1.74		6.04
Daily mean (m^3/day)	0.31	0.48	0.32	0.35	0.42	0.38	0.22

Figures 4 and 5 show the daily variation of gas produced for some mixture ratios. The variation shows respective peak values are obtained followed by a general decline. There are noticeable subsidiary oscillations in the gas produced for some ratios. This could be due to breakdown of easily digestible materials such as fats, sugars and carbohydrates while the lower gas produced could be due to presence of substantial percentages of less digestible materials such as cellulose and lignin.

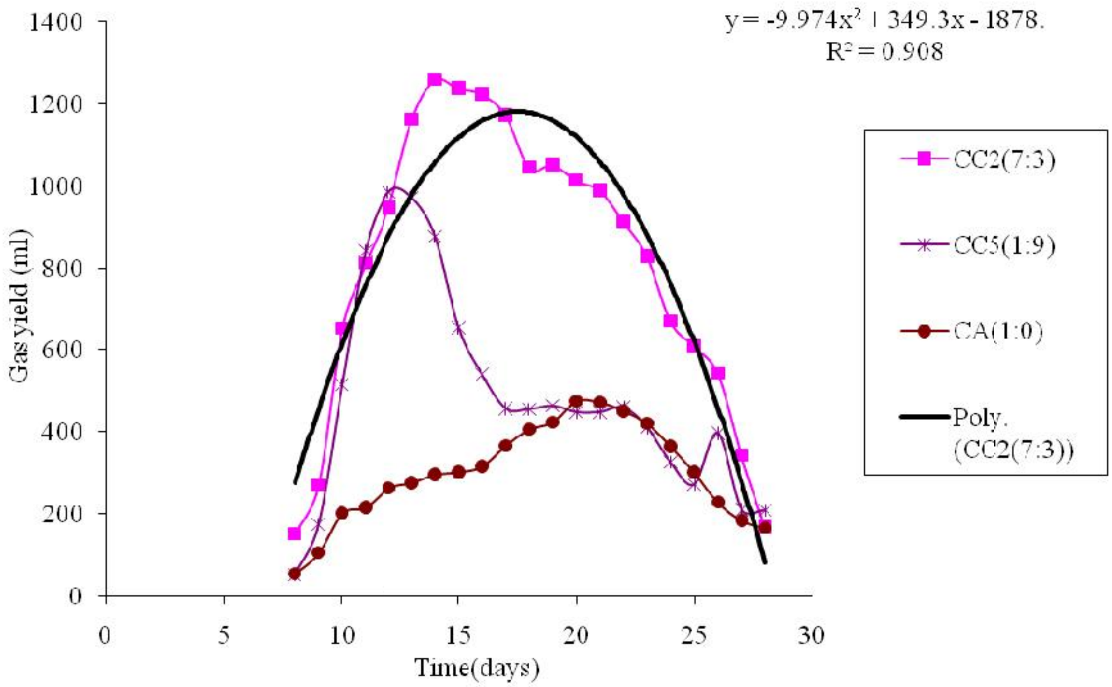

Figure 4: Daily variation of gas produced for mixture ratios CC and CA

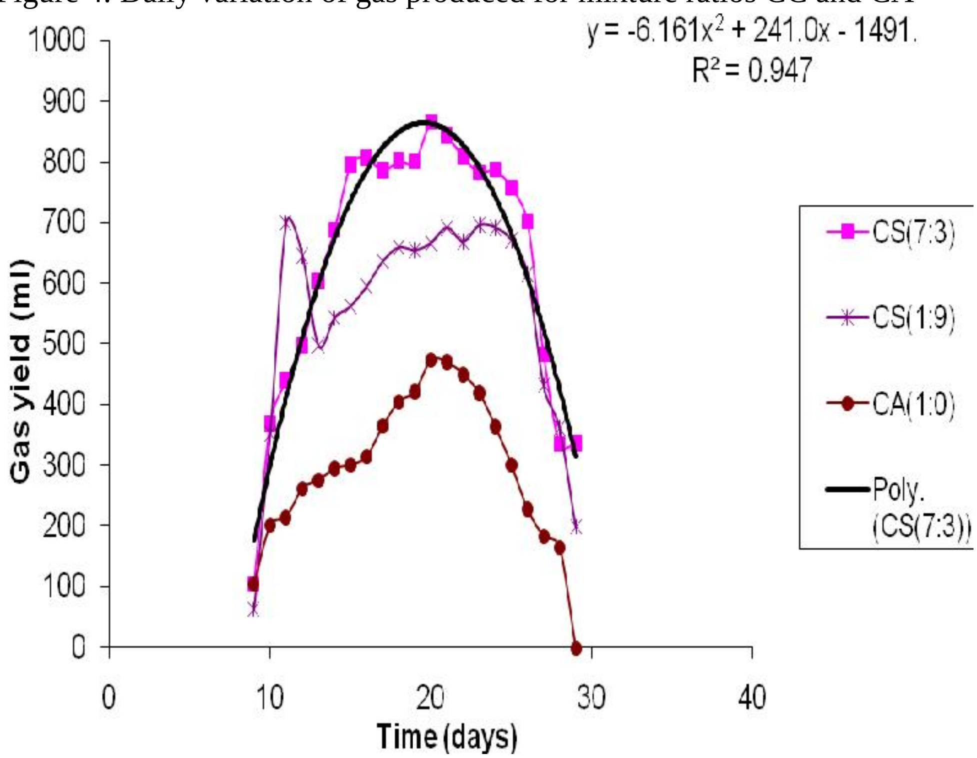

Figure 5: Daily variation of gas produced for the mixture ratios CS and CA

The scatter lines for the ratios 7:3 and 1:9 follow the same pattern though one at a lower level. This suggest similar pattern in the bacteria activity of the substrates for both the ratios. The results agree with the findings of Maramba (1978) and Chowdhurry (1987). There are two regions of higher rate of biogas production at short times of at least 22 days and lower production at longer times of 32 days.

The findings are further confirmed by the results obtained for the gas production to reach the peak for each mixture ratio as shown in Table 4. The peak gas production was achieved between the 13th and the 21st day for the CC; and between the 20th and the 23rd day for the CS. This implies that the mixture ratios of CC had more easily digestible materials resulting in shorter digestion periods than that of CS.

Table 4: Time taken (days) for the Mixture ratios to reach peak gas production

Mixture	Ratio					
	9:1	7:3	5:5	3:7	1:9	1:0
CC	21	14	19	18	13	20
CS	23	20	23	23	23	20

4.0 Conclusions and Recommendations.

The research was primarily conducted to analyse the rate of biogas production from selected livestock waste mixtures in varying ratios. It was found that, all CC and CS mixture ratios tested yielded higher amounts of biogas than CA. It was also observed that most of the mixtures enhanced the rate of digestion. To this endeavour, it can be concluded that, mixing cow dung with chicken or sheep droppings improved the rate of biogas production compared to using cow dung alone. However, further studies need to be conducted to include the quality of biogas yields.

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