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Household Perspectives and value of Low-Carbon off-grid Energy Technologies in the Kenyan Rangelands

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***Abstract*—*Kenya is constrained by low rural clean energy access, particularly among communities in remote settings. The objective of this study is to evaluate the social value and preferences of low-carbon off-grid technologies by households in Kenyan rangelands as an alternative to the national grid for powering isolated low-income communities. To this end a household survey was conducted on a settlement in Laikipia North using interview schedules to assess demographic characteristics, energy consumption patterns and average expenditure on traditional fuels, clean energy awareness, preferences and willingness to pay. Key findings revealed that residential off-grid clean energy options studied were largely found to be socially viable, as rural households are willing to switch from high-carbon fuels, but affordability is a key concern. The most acceptable off-grid low-carbon lighting technologies for remote low-income homesteads are Pico solar lamps and solar panels, while portable Liquid petroleum gas stoves and clean cook-stoves were found to be the most acceptable technology for low-carbon cooking at household level due to the relatively low cost, and portability factors which are favorable for pastoralist communities. It was also found that despite the Kenyan Government commitment towards a green economy, a change in policy direction would be necessary to ensure that there is inclusive access to clean energy through awareness programs and targeted financial interventions in support of low-income energy-deprived communities.*

Keywords*—*Acceptability, Energy, Low-carbon, households, Kenya, Rangelands

I. INTRODUCTION

Clean energy has a high potential to contribute to sustainable development and household welfare, yet just over a third of Kenya's population has electricity access with less than 40% rural access to clean energy (World Bank, 2016). The low rural access to clean power, in addition to constraining development, and provoking environmental degradation, compels communities to consume high carbon fuels which pose health risks, largely affecting women and children, due to indoor pollution (WHO, 2016). The country is highly vulnerable to impacts of climate change, with more than 80% of the country being arid and semi-arid rangeland (Mwangonbe et al. 2011), characterized by scattered settlements of low-income communities and poor infrastructure development. Out of Kenya's total greenhouse gas emissions (GHG), 75% arises from land use, forestry and agriculture (Government of Kenya, 2015), largely as a result of dependence on wood fuels by a large segment of households, posing an environmental threat to fragile rangelands.

Despite the scale-up of grid-based rural electrification through existing legal reforms, there will be a large portion of unreached rural households, particularly those located in isolated settings due to high poverty levels and the nature of remote scattered settlements (IFC, 2011), calling for decentralized or off-grid alternatives in supplying clean power to energy deprived households. A key issue influencing the effective implementation of decentralized clean energy programs and rural energy expansion goals, according to Devine-Wright (2008) is social acceptance.

Various studies have been done to evaluate the social acceptability of decentralized power installations. Assefa and Frosttell (2007) describe various determinants for assessing the social viability of renewable technologies, which include knowledge and household perceptions relating to the potential risks and benefits associated with emerging energy technologies. Findings reveal that respondents in remote settings have relatively low levels of awareness about off-grid energy technologies making it difficult to rank them according to preferences, and advocates for the engagement of community groups and aggregating results with economic performance indicators. Devine-Wright (2011) notes that the "depth of attachment between people and the environments in

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which they reside can either motivate support or opposition to proposed energy technology development", thus, the perceived benefits, willingness to pay energy costs and trust all play a vital role. To support this premise, Vorkinn and Riese (2001) reveal how public acceptance for decentralized energy installations is determined by the depth of attachment to the affected site, a factor which is observed to have more significance compared to basic demographic features.

Hirmer and Cruickshank (2014) argue the essence of user value in assessing the social viability of alternative power supply projects. They propose that "By targeting the values of the end-users the sustainability of rural electrification projects will be better ensured". Study findings reveal the significance of end-user value perceptions to the success of rural electrification projects, beyond the commonly used indicator of technical or financial value. Studies by Department of Trade and Industry, London (2003) reveal that "public knowledge and understanding about renewable energy are critical to the social acceptance of energy projects". Findings also show that individuals and communities who are well informed are significantly more accepting towards renewable energy technologies.

The aim of this study therefore, is to assess the value and preferences of residential low-carbon off-grid energy technologies by households in remote rangelands of Kenya. Specifically, this article sought to determine basic rural household demographics, energy consumption, experiences and expenditure, awareness and willingness to pay for clean energy sources, preference ranking and trade-offs regarding off-grid clean energy products for lighting and cooking. The remaining part of this paper is organized as follows. Section II summarizes the research methodology. Section III discusses the results and section IV presents conclusions. The study is important as it serves as a basis for informing national and international policy makers and energy sector actors on the socially viable low-carbon energy programs for developing unreached rural areas in a sustainable way while scaling-up inclusive clean energy access in transition to a green economy.

II. RESEARCH METHODOLOGY

2.1 Study area

A descriptive research design was adopted for the study. The study area is Naibunga Conservancy located in Laikipia North. The size of the Conservancy is 477 square kilometers with a total population of 20,000 (Northern Rangelands Trust, 2016). The specific community sampled was from the Koige Settlement, which has a size of 5.4 square kilometers and a population of 1200 people with 250 households (Northern Rangelands Trust, 2016). The study targeted a sample of 151 households through systematic random sampling. This rangeland settlement was selected as it met the basic socio-economic criteria of an energy deprived group with limited power grid access, scattered, low-income settlements, exposed to arid climate conditions and limited access to markets and basic social services

2.2 Data collection and analysis

Data for the household survey data was collected in 2017 using face to face interviews conducted with the use of an interview schedule targeted at generating data on the demographic characteristics of households, social awareness and acceptability of clean energy, energy use and perceptions regarding the risks and benefits of energy technologies. Descriptive statistical analysis was performed with the aid of SPSS software and summarized into frequencies, mean and percentages in order to explain the socioeconomic status, energy use and preferences of households the social ranking and trade-offs of clean energy technologies. For the analysis of variance and ranking of household preferences for clean energy technologies, the non-parametric Friedman rank test was used as it is suitable for analyzing ordinal data and generating a mean ranking of technologies. To further test the degree of concordance between respondents the Kendall's Concordance Coefficient W test was conducted. This is a normalization of the Friedman statistic which is used to test the strength of agreement between respondents (Pett, 1997).

III. RESULTS AND DISCUSSION

3.1 Demography of households

Among the households sampled 64.9 are male and 35.1 female household heads. The main livelihood is livestock herding, reported by 23.8% of respondents, subsistence farming (22.9%), business (19%), with 14% unemployed and 4.3% in casual employment. This indicates that the community is heavily reliant on livestock and agricultural output for their livelihood and, given the semi-arid nature of the area, exposes households to low erratic income and nomadic practices in search of more fertile pastures. The reported household income reported by 56% of respondents is below US$ 30 monthly, well below the global poverty line of $1.9 a day (World Bank, 2015), indicating a significant barrier towards clean energy access. Seventy percent of households reside in two-roomed semi-permanent housing structures, exposing them to overcrowding and health and safety risks arising from indoor pollution and open fires.. Eighty three percent of respondents stated that they are aware about clean energy, while 17% of houshold heads, all male, stated that they were unaware and largely indifferent towards clean energy. This indicates the high potential of women, particularly within the framework of women's

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groups, to expand clean energy access to households. The main sources of clean energy awareness are radio, cited by 22.9% of respondents, television (19.2%) and marketing by local vendors (22.5%), highlighting the role of the radio and informal sector in creating clean energy awareness.

3.2 Household fuel use for cooking and lighting

Table 1 summarizes the household fuel use for cooking and lighting, indicating a high dependence on high-carbon fuels, leading to adverse health and environmental effects.

Tabel.1: Household energy use

Fuel use	Fuel type	Percent household
Cooking	Firewood	80.0
	Charcoal	9.3
	LPG stove	5.3
	LPG large gas cooker	2.6
	Electric cooker	2.6
Lighting	Kerosene lantern	53.0
	Tin kerosene lamp	20.5
	Diesel generator	6.0
	Solar panels	4.6
	Battery torch	4.0
	Solar Pico lamp	3.7
	Car batteries with LED lights	3.3
	Candles	2.0
	Electric lights	2.0

Source: survey data

Study findings reveal that the mean household monthly expenditure on high-emission fuels is US$ 12 with a standard deviation of 1,166.3. Given an average household income of below US$ 30 monthly, expenditure on high-carbon fuels represents over 30% of average household income, implying adverse impacts on the financial welfare of energy deprived households, as less income remains for food, health care, education and savings.

3.3 Perceived challenges of high carbon fuel use

The main concern of respondents who principally rely on high-carbon fuels is high fuel costs (44%) followed by health risks of indoor pollution (24.2%) and safety risks from open fires (7.9%). In order to quantify the concerns of respondents, the social costs of high-carbon fuel use, related to 2016 experiences is summarized in Table 2, indicating substantial income spending on healthcare.

Table.2: Perceived social costs of high-carbon fuels

Fuel-use challenge	Nature of risk	Percent household	Average cost (US$), time or incident
High fuel cost	Income deficiency	44	$ 12 monthly
Health risk	Allergies	24.2	$.13 monthly
	Respiratory infections		$.6.3 monthly
	Asthma		$.11 monthly
	Eye infections		$.10.4 monthly
Accident risk	Burns	7.9	15 incidents
	Suffocation		1 incident
Limited fuel-hours	-	5.5	2.5 fuel-hours daily
Fuel collection delays	-	5.2	2 hours daily
Restricted fuel access	-	5.3	-
Limited study hours	-	5.0	2.5 fuel hours daily
Seasonal supply	-	2.9	-

Source: survey data

3.4 Proximity to the nearest power grid network

Respondents estimated the distance from home to the nearest grid network or electricity pole, indicating that 52% of respondents reside 10-20 kilometers (km) away from the nearest grid line, with a significant number (13.9%) residing 20-30 km away from the nearest grid network. Figure 1 compares the proximity and connectivity of residents to the nearest power grid network. A significant number of households (27%) live less than a kilometer from the power grid but only 2% are connected, indicating that proximity to the power grid is a positive but not sufficient factor in rural electricity connectivity due to the low and intermittent income and pastoral lifestyle of households which is a significant barrier to clean energy access.

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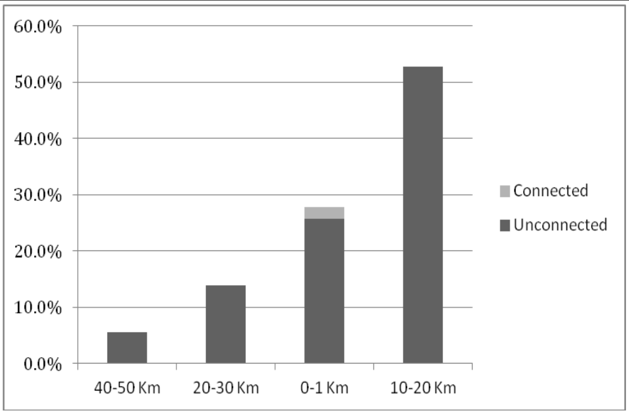

Fig.1: Distance and connectivity to the power grid network

3.5 Household clean energy preferences for lighting

In order to assess the social preferences, trade-offs and ranking of clean energy projects, households selected from a range of clean energy products which include wind turbine, electric lighting, solar photovoltaic (PV), Pico solar, which are small rechargeable lamps with capacity for cell phone charging, and battery powered torches. To facilitate the social ranking of the most preferred lighting technology a Likert scale ranging from 1 (least preferred) to 6 (most preferred) was adopted. The Friedman rank test was adopted to derive the mean ranking of technologies, summarized in Table 3.

Table.3: Preference rating of clean lighting technologies

	Technology selection by number of households					
Score	Electric lights	Solar PV	Solar Pico	Wind turbine	Gas lamp	Battery torch
6	60	27	10			
5		34				
4			3	28	3	
3			9		19	
2			15	3	9	3
1	8			3	9	46
Total score	368	332	129	121	96	52
Mean rank	5.46	5.25	3.3	3.4	2.4	1

Source: survey data

The social ranking of clean energy technologies is presented in Figure 2. The most preferred modern lighting technology is electrical lighting, with a total preference score of 368 followed by solar panels with a preference score of 332 and Pico solar lamps with a score of 129. The least preferred lighting source is the battery torch with a score of 52 and gas lamps, with a score of 96. A Friedman test (χ^2 (5) =151.37, p = 0.000) revealed a significant difference in the distribution of respondents between the groups of clean lighting technologies. Further testing using the Kendall's W test (Kendall W= 0.890) indicated a highly significant level of consensus among respondents on the rating of clean lighting technologies.

The most significant attributes of electricity, as reported by respondents, are ease of doing business (23%) and affordability of power (19.8%). Solar products are preferred due to affordability (43%) while an equal number of respondents (17%) cited reliability of power supply and the absence of rationing as a reason for their preference. This implies that, in the absence of grid electricity, households are willing to trade-off the benefit of ease of doing business in their selection of alternative off-grid clean energy lighting sources.

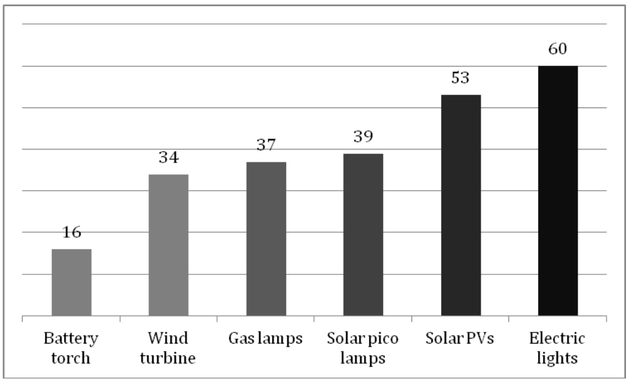

Fig.2: Household ranking of clean energy technology for lighting

3.6 Clean energy preferences for cooking

Respondents, classified by gender, ranked their preferences of clean energy technologies for cooking among a variety of technologies such as electric cookers, biogas digesters, clean energy cook-stoves and portable liquid petroleum gas (LPG) stoves. The inclusion of electric cooking implements evaluates the trade-off in perceived attributes of clean off-grid products as a substitute to grid electricity. From the selection of 4 cooking implements, respondents ranked their preference from a score of 1 (least preferred) to 4 (most preferred) the results of which were subjected to a Friedman test to establish a mean ranking of preferred technologies as summarized in Table 4.

Table.4: Preference rating of clean cooking technologies by gender

	Technology selection by number of respondents							
	Electric cookers		LPG gas stove		Improved cookstove		Biogas	
Score	M	F	M	F	M	F	M	F

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4	44	23	14	2	2	3		
3			13	2	7	8	7	3
2			10	2	6	6	11	5
1	9	3	11	1	5	4	12	10
Total score by gender	185	95	126	17	52	52	55	29
Total score	280		143		104		84	
Mean rank	3.46		3.22		2.5		2.18	

The most preferred energy technology for cooking purposes is the electric cooker, with a male preference score of 185 and female score of 95. This is followed by LPG portable gas stoves with a male preference score of 126 and female score of 17 indicating a high male preference for modern cooking technologies, like electricity and gas. Clean energy cook stoves are ranked third with a score of 104 selected by a proportionate number of male and female respondents with an equal preference score of 52, indicating a strong potential for household market demand by women. The least preferred household energy source for cooking is biogas fuel reporting a score of 55 and 29 by male and female respondents respectively, reportedly due to the high equipment cost and cumbersome task of operating the cooking implement. Results subjected to Friedman test (χ^2 (3) = 77.09, p = 0.000) revealed a significant difference in the distribution of responses between the different groups of cooking technologies. Further testing using the Kendall's W test (Kendall W= 0.627) indicated a fairly significant level of consensus among respondents on the rating of clean cooking technologies. Results showing the social ranking of technologies by gender are summarized in Figure 3.

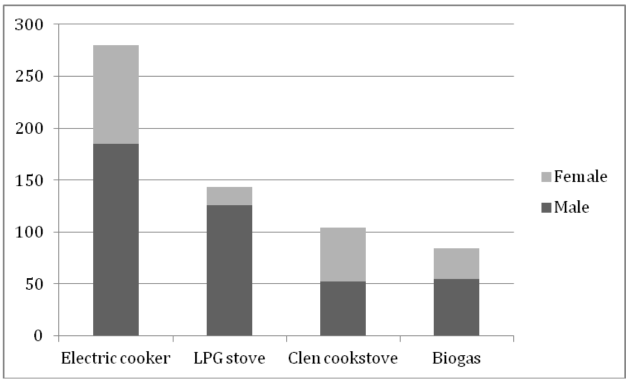

Fig.3: Ranking of clean off-grid cooking technologies by gender

The ranking of clean energy preferences by gender implies that rural male-headed households have a high preference for electricity and LPG gas, while women, who are most likely to be the end users, have a high preference for clean cook stoves, which are perceived to be more accessible and practical for household use. Key stated attributes for electricity for cooking are time saving benefits (38%) and instant power access, without the need for fuel refills (19%). The stated principal attributes of gas stoves and clean cookstoves are affordability (33.6%) and portability (27.2%) which is perceived as convenient for a pastoralist lifestyle. In the absence of electricity access, this implies that households are willing to trade-off the perceived time-saving attribute of grid power in the selection of alternative clean off-grid cooking resources.

3.7 Perceived household benefits of clean energy

Table 5 presents household perceptions regarding clean energy benefits. Findings reveal that that 14.6% of respondents are optimistic about the general household benefits of clean energy, which include income savings, clean and safe environment, time-savings in collecting fuel, increased fuel hours and study hours. The most significant benefit mentioned from the use of clean energy is income savings, by 31.8% households who expect to save 60% of their income. The perceived benefit of a pollution-free environment is cited by 12% of respondents, with 70% savings on health expenditure. In addition safe environment, with a 60% reduction in accidents, is also cited as a benefit by 9.9% of respondents.

Table.5: Perceived social benefits of clean off-grid energy technologies

Clean energy benefits	Nature of benefit	Percent	Average gains
Income savings	Reduced fuel expenditure	31.8	60% savings
General welfare	All benefits	14.6	-
Reduced indoor pollution	Reduced health expenditure	12	70% savings
Safe to use	Reduced accidents	9.9	60% reduction
Increased fuel output	Increase in daily fuel hours	6	3 hours daily
Business productivity	Increased business output	6	30% expansion
Time-saving	Reduced fuel collection time	5.8	1.5 hours daily
Improved study hours	Increased daily study hours	4	3 hours daily

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Agricultural productivity	-	4	25% expansion
Phone charging facility	Increased daily charging hours	2	3 hours daily
Fuel more accessible	-	2	-

Source: survey data

Respondents, however, cited perceived barriers to clean energy access (Figure 4). Low income is the principle barrier, cited by 55% of respondents, who reported that the high cost of clean energy equipment and connectivity are significant constraints. Remote location of households was cited as a barrier by 10.6% of respondents, making it difficult to access clean energy markets. The temporary nature of dwellings and nomadic lifestyle was also perceived as a barrier to clean energy access by 9.3% of households. Institutional and government failures were noted by 8% of respondents, who felt left out of national clean energy expansion programs.

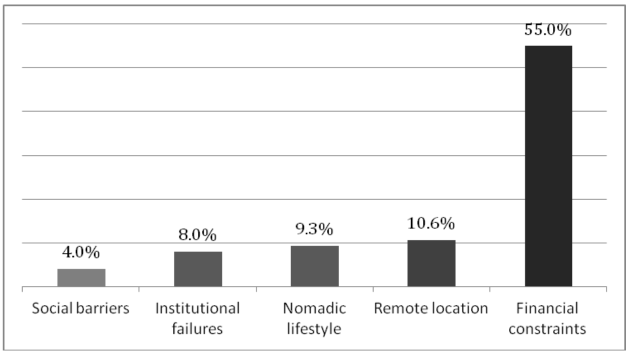

Fig.4: Perceived household barriers to clean energy access

3.8 Willingness to pay for clean fuel

The evaluation of willingness to pay for clean fuel reveals household energy consumption preferences when given an opportunity and financial capability to switch to affordable clean energy sources. Results revealed a wide consensus among 89.4% households regarding willingness to pay for clean energy if it is available and affordable. This implies that rural low-income households aware of clean energy would be willing to upgrade from traditional fuels, but are constrained by economic factors.

Respondents that were willing to switch revealed the expected sources of finance for clean energy transition (Table 6). Most respondents (45.7%) expected financial support from the government and non-governmental organizations. Other expected sources of finance were personal savings (12.5%), loans from self-help groups (9.4%) and sale of livestock (8.8%). A significant number of respondents (21.9%) were unsure about potential sources of finance for clean energy, implying that they were not optimistic about overcoming financial barriers to clean energy.

Table.6: Expected sources of finance for clean energy

Expected sources of finance	Percent household
Government and NGO support	45.7
Uncertain about financial sources	21.9
Personal savings	12.5
Loans from self-help groups	9.4
Sale of livestock	8.8

Source: survey data

In the absence of clean energy grants, 36.3% of household heads stated that they would expand their personal savings for future access to clean energy, 33.3% intended to continue using traditional fuels indefinitely, while 11.1% preferred to sell their livestock. A few respondents (5.5%) opted to seek credit facilities from community groups, while 13.8% were uncertain about alternative financial options available to them, implying that most low-income rural households would be likely to sustain the consumption of high-carbon fuels, reinforcing the need for financial assistance to bridge the clean energy gap.

3.9 Discussion

Low-income households in remote rangelands have a strong reliance on firewood, charcoal and kerosene for cooking and lighting, leading to forest cover depletion, adverse health and safety impacts and financial instability, with over 30% income expenditure on traditional fuels. The strongest concern among households reliant on high-carbon fuels is high cost of fuels and healthcare costs, the most significant being allergy related health problems, costing low-income rural households an average of US$ 13 per month, about 43% of income. There is a high level of awareness about clean energy, especially among women, and a strong preference for electricity for lighting and cooking, particularly among male-headed households, despite the low connectivity rate. In the absence of electricity, households are willing to trade-off ease of doing business and time-saving attributes of grid power in their selection of alternative off-grid clean energy sources.

Household off-grid preferences, therefore, reveal that clean technologies, such as solar home systems, LPG stoves and improved cookstoves have the highest value for remote, largely pastoral households due to the substantial level of social acceptability and willingness to upgrade. In addition, women, due to their comparatively high level of awareness about clean energy and its benefits, have a relatively stronger potential to transition to clean energy compared to their male counterparts.

Most households, however, are inhibited by low incomes and will require State financial support in partnership with private sector initiatives, in order to accelerate inclusive access to clean energy. Potential end-users perceive clean energy to be electricity and are not well educated about low-carbon off-grid products in the market thus cannot make informed purchasing decisions and are likely to buy low-quality products or retain the use of high-carbon fuels. This confirms findings by DTI (2003) and Hirmer et al (2014) that user value and public understanding are crucial to off-grid clean energy acceptance and transition by rural communities.

IV. CONCLUSION AND POLICY IMPLICATIONS

Study results reveal positive household perceptions regarding off-grid clean energy transitions, especially among women. In the absence of grid power, there is a high preference for solar products, gas stoves and improved cook-stoves, but low household income, remote location and lack of awareness, with a measure of indifference, among largely male-headed households is a significant barrier to access. In order to expand inclusive clean energy access to remote households, national grants and targeted subsidies, including tariff exemptions, for clean energy technologies can be extended through budgetary allocations to support investors, informal vendors and deprived households

To further support the up-take of clean off-grid energy, the State, through partnerships with the private and financial sector, supported by national and international grants, can provide attractive financial initiatives, such as low-interest clean energy loans or easy hire purchase programs for households. Financial initiatives should also be targeted towards women through women's groups, since they have a strong potential to expand clean energy access to remote rural areas. Potential financial actors include cooperative societies, private developers, non-governmental organizations and micro-finance organizations.

A household off-grid clean energy fund, sustained through national and international funding, including clean development mechanisms, can be developed to accelerate investment and delivery of clean power to remote rural areas. This fund can be used for clean energy grants to support energy sector actors, low-interest credit facilities for households and women's groups, training and awareness programs.

To fill the knowledge gap among remote rural communities and create awareness about the financial and health benefits of clean energy, national awareness and community education programs can be implemented through public-private partnerships with the local media and informal traders, who play a strong role in creating clean energy awareness.. This includes initiatives to build stakeholder capacity and make communities understand the essence of engaging national authorities in the policy and planning process, as this would translate into inclusive clean energy access.

REFERENCES

[1] Assefa, G., Frosttell, B. (2007). Social sustainability and social acceptance in technology assessment: A case study on energy technologies. *Technol. Soc. 29 (1),* 63-79

[2] Department of Trade and Industry. (2003). *Energy white paper: Our energy future, creating a low-carbon economy*. DTI, London

[3] Devine-Wright, P. (2008). *Reconsidering public acceptance of renewable energy technologies: A critical review.* Department of Applied Economics Occasional Papers No 68. Cambridge University Press

[4] Devine-Wright, P. (2011) Place attachment and public acceptance of renewable energy: A tidal energy case study. *Journal of Environmental Psychology, 21 (4)* 336-343

[5] Government of Kenya (2015) *Kenya green economy strategy and implementation plan (GESIP)*, Kenya

[6] Hirmer, S. and Cruickshank, H. (2014) User value of rural electrification. An analysis and adoption of existing models and theories. *Science Direct.* Retrieved from http://www.sciencedirect.com/article/pii

[7] International Finance Corporation (2011) *Lighting Africa: Policy report note, Kenya.* IFC, Washington DC.

[8] Mwangombe, A.., Ekaya, W., Muiru, W., Wasonga V., Mnene, W., Mongare, P. and Chege, S. (2011) Livelihoods under climate variability and change: An analysis of the adaptive capacity of rural poor to water scarcity in Kenyan drylands, *Journal of Environmental Science and Technology, 4,* 403-410

[9] Northern Rangelands Trust (2016) *Rangelands of Northern Kenya,* NRT, Laikipia

[10] Pett, M. (1997) Non-parametric statistics in healthcare research. *SAGE* 28 March 1997

[11] World Bank (2015) *Global poverty line update.* Retrieved from http://www.wourldbank.org/povertybrief

[12] World Bank Data (2016) *Access to electricity rural*. Retrieved from http://www.data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS

[13] World Health Organization (2016) *Indoor air pollution and health.* WHO Fact Sheet No 292.

[14] Vorkinn, W. and Riese, H. (2001). Environmental concern in a local context: The significance of place attachment. *Environ.Behav. (33)*, 249-283.