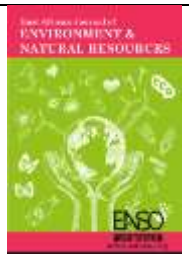

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Original Article

Environmental Impacts of Household Solar Energy Use Adoption in Murang'a County, Kenya

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Households, Solar Energy Use, Positive Environmental Impact, Transition theory, Adoption.

ABSTRACT

Although Kenya enjoys an abundant of sunshine throughout the year, most households in counties like Murang'a still use non-renewable sources of energy for their energy needs. Globally, households account for approximately 40% of energy consumption per annum with most needs being heating, air conditioning, cooling and lighting. Environmental management is now a global goal with over 197 nations endorsing a framework that promotes positive environmental impact through renewable energy and reduced C02 emissions during COP21 in Paris. This research mainly focused on positive environmental impacts of solar energy use adoption within households in Murang'a County, Kenya. Guided by the transition theory, the research applied anticipated transitions to discuss different aspects of solar energy use adoption in the county and the impact they have on the environment. This qualitative and quantitative study sought to explore perspectives of various households on solar energy use and how the adoption has positively impacted the environment. The data used for the study was collected from 384 randomly selected households in four constituencies in Murang'a County. The findings of the study established low adoption rates of households' solar energy use and a direct correlation of adoption levels with the awareness levels for most of the study population. Moreover, the study confirmed the hypothesis that solar energy use adoption in households positively influenced environment through management strategies and improved livelihoods. Furthermore, policy measures to support training as well as financial support would go a long way in increasing uptake of solar energy use in households in Murang'a County thus positively influencing the environment through management strategies such as renewable energy use.

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INTRODUCTION

Kenneth *et al*., (2020) argues that social and economic development globally largely relies on energy. High-energy consumption especially in households worldwide has, however, resulted to negative environmental impacts like pollution, climate change and in turn affected human health through emission of greenhouse gases (GHG) like carbon dioxide ($C0_2$). Netherlands Environmental Assessment Agency, (2021), for example, reported that global $C0_2$ emissions from households increased significantly between 2017 and 2020 globally with highest emissions experienced in Asia and the United States of America. Diversification of household energy sources to environmentally friendly sources like biomass energy, solar energy, wind energy and hydropower improves living standards through social and economic growth, health and through environmental management through reduced $C0_2$ emissions. According to World Health Organization, household air pollution from use of fossil fuels like wood fuels and kerosene in developing countries will account for over 1.5 million premature deaths annually by the year 2030 if cleaner energy sources are not adopted (Shu-Wen. N, 2012).

According to OECD (2021), mitigating environmental pressure caused by energy consumption requires a lot of research and reporting on efficient interventions made in different parts of the world. Households are an important group in environmental management as they account for approximately 15-20% of total energy requirements globally. Total household energy consumption in American and European households is estimated to be 30%; in China, it is estimated to be 11% of the country's total energy consumption; and in most developing countries like Kenya, it is estimated at 14% of total energy consumption according to Jonathan *et al*., (2018). Households consume energy indirectly through production, goods disposal and transportation but mainly directly through cooking, lighting and ventilation. Cox, S. (2016) argues that this household energy consumption has led to serious environmental problems worldwide especially carbon emissions that negatively affect the environment with households in the US, for example, accounting for almost 38% of total CO_2 emissions in the country. The major goal of most global energy and environment policies is therefore geared towards energy conservation in households through changing their energy use behavior. While behavior change in energy consumption is a focal point in environmental management, it is important to note that lack of knowledge, high installation costs, and government support are global hindrances in adoption of energy sources with lower $C0_2$ emissions in most households (Lindah Steg, 2008).

Per Anker-Nilssen (2003) states that household energy consumption patterns have the potential to impact the environment positively. Through more efficient and renewable energy use, approximately 27% of households' energy currently can be saved resulting to positive impacts in the environment like mitigating climate change. Kaile and Shanlin (2016) argue that in the European Union (EU) countries for example, a study shows that behavioral change in energy consumption of households and technological advances results to annual energy savings that could be as high as 1399kWh. In Norway, average

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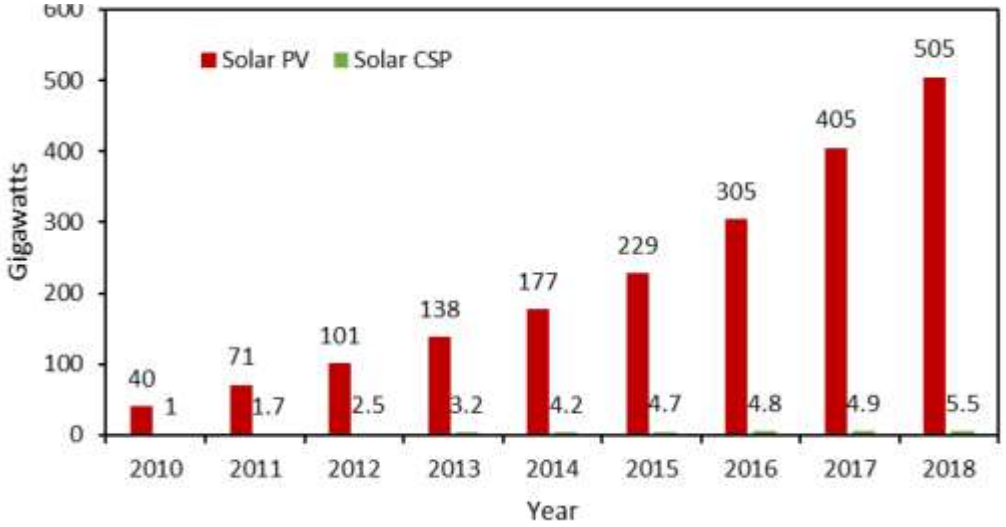
annual growth of stationery households' energy had reduced by approximately 1.9% annually from the 1990s- 2014 due to the incorporation of energy efficient measures towards environmental management. In developing countries, household energy consumption results in serious damage to the eco-environment as most household use unconventional energy sources like wood fuels, kerosene, diesel and LPG for most household energy needs. By changing and understanding energy consumption behaviors, household can effectively promote energy conservation and improve efficiency that in turn results to environmental conservation. Adoption of renewable energy sources in households is viewed as one of the sure ways to positively influence the environment (Barnes, 2007).

Solar energy technologies (SETs) are divided into two categories; concentrating solar power (CSP) and solar photovoltaics (PV). In Solar CSP, mirrors are used to reflect & focus sunlight in order to generate heat converting it into solar power whereas PV cells directly convert solar radiations into electricity. Installation of solar energy can be on large scale depending on its location and size or can be independent and off the grid (typically <1 MW) and are mainly integrated in buildings. Solar photovoltaics (PV) is the technology used in most households that have adopted solar energy use globally. In 2018, global solar PV markets worldwide increased by 100 GW reaching a total installed capacity of 505 GW. In the same year solar CSP accounted for 5.5GW equivalent to below 1.1% of the capacity installed globally. Off-grid solar PV systems in developing countries continues to be the main contributor of rural electrification with 5% of the total household population in Africa believed to be powered by off-grid PV systems (Fares and Webber, 2017).

Figure 1; Solar PV & Solar CSP globally. (Hamed and Alshare, 2022)



Environmental impacts of solar energy use adoption

Solar energy, according to Kaygusuz (2009) gives a great alternative to energy sources that are carbon-intensive like fossil fuels such as firewood, diesel and kerosene. Solar energy has a great potential to contribute and positively impact the environment through mitigating climate change by reducing pollution emissions from carbon or toxic gases-intensive sources. In addition to this Williams *et al*. (2012) estimates the total amount of CO_2 emissions globally that can be avoided through solar energy use adoption can range from 6.5% to 18.8% if more than 50% of household energy sources in a country was generated through solar photovoltaics (PV). Research shows that solar energy positively impacts the environment in many ways among them reducing pollution and reducing GHG emissions thus leading to improved quality of life; reducing dependency on fossil fuels through adoption of a more reliable and clean source of energy. Solar energy use adoption helps in reclamation of degraded land through ways of

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land reuse like setting up of solar plants, and improving the quality of water resources and food security through the application of SETs (Abdeen, 2009).

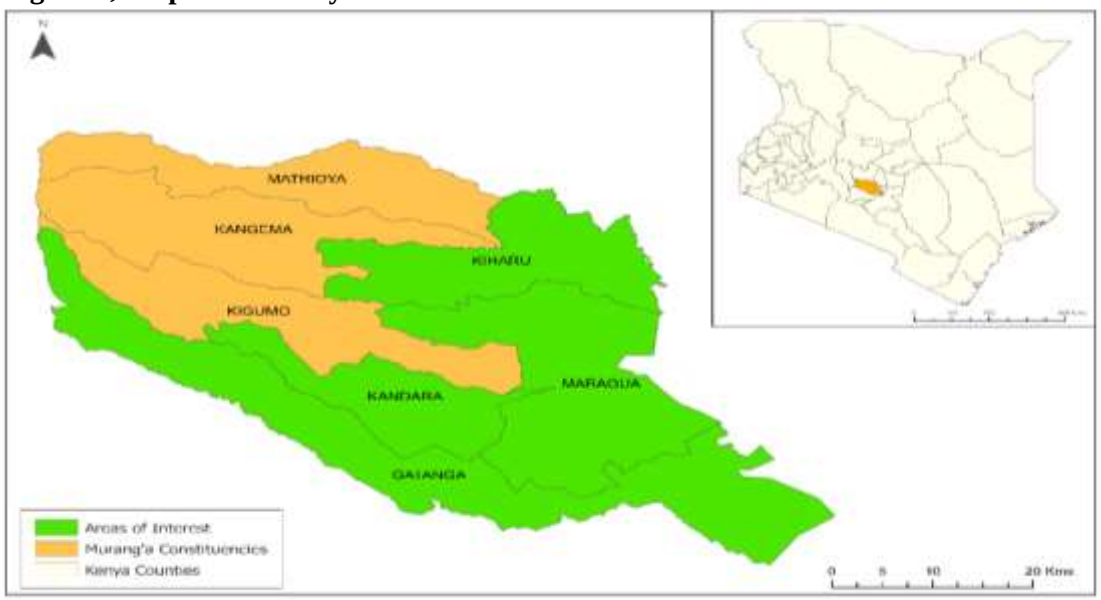
Theoretical Framework

The study followed Roger's & Marshall's (2003) diffusion theory of innovation which applies the terms "innovation" and "technology" as synonyms in defining the diffusion theory stating that adoption is a full use of an innovation and rejection is a decision not to adopt. The diffusion theory therefore looks at diffusion of an innovation like solar energy use and its subsequent benefits through elements like social systems, communication channels, innovation and time. Transition theory was also followed in the study as it argues that the system that any society bases itself must transition towards a future that is more sustainable including technological, social, economic and political in achieving an environment that is positively impacted. Anticipated transition of the transition theory were the main guides as they dictate that adoption of solar energy use in households within Murang'a County would yield positive impacts to the environment (Retollaza, 2011).

METHODOLOGY

Area of Study

Figure 2; Map of the Study Area



This research was carried out in Murang'a County, one of the forty-seven administrative counties in Kenya. The main objective of the study was to explore the environmental impacts of household solar energy use adoption in Murang'a County, Kenya. The study's main hypothesis argued that solar energy use adoption in households in Murang'a County has led to positive effects on the environment. Murang'a County has an area of 2558 sq Km and is located approximately 85 km northeast of Nairobi, Kenya's Capital City. The County is situated 3353m above sea level (ASL) in the West along the Aberdare Ranges's slopes and in the East 914m ASL (Gitone, 2014)

All rivers in Murang'a County flow from the Aberdare Ranges joining Tana River Southeastward. Three climatic regions divide Murang'a County namely: semi-arid climate in the eastern region, equatorial climate in the western region and sub-tropical climate in the central region. According to Murang'a County Integrated Plan (MCIP), (2018), the County experiences cool climate most of the year with Kangema, parts of Kigumo, Gatanga, Kandara, Mathioya and Kiharu constituencies experiencing wet and humid climatic conditions due to the influence of Mt. Kenya and Aberdare Ranges' while parts of Maragwa, parts of Kigumo, parts of Kiharu receive less rainfall. The tropical

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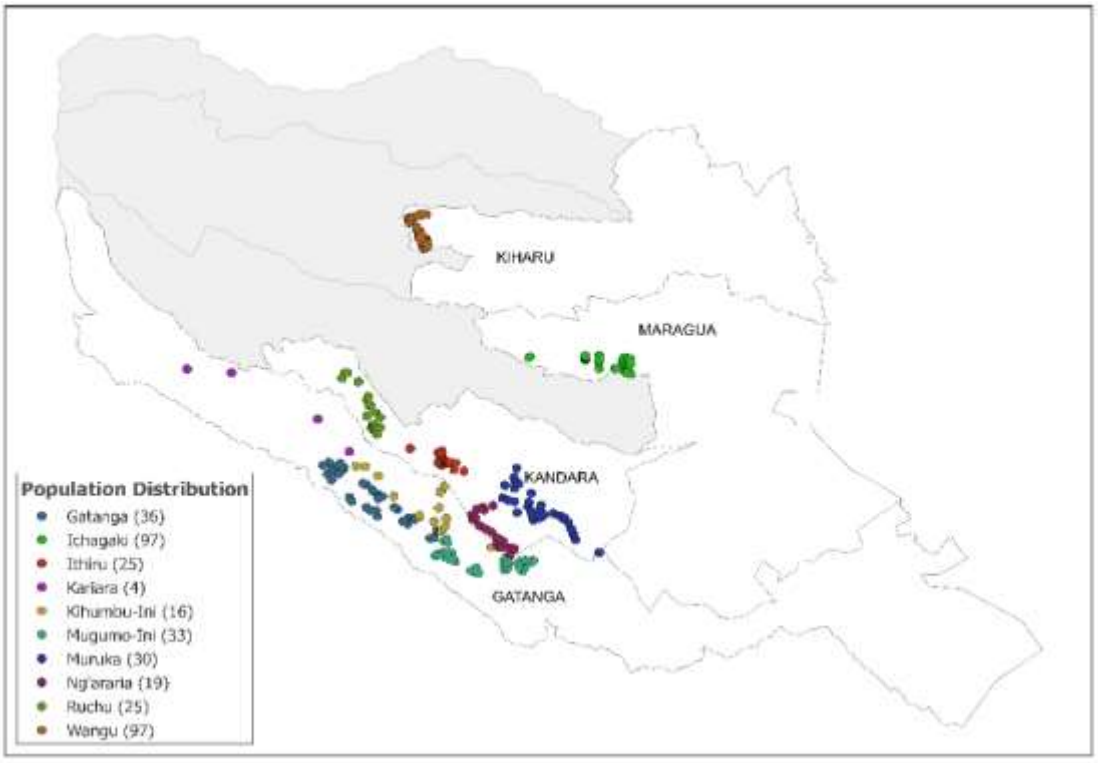
conditions of the county ensure that sunshine is experienced for over 300 days in a year for at least 8 hours a day equating to approximately 2400 hours of good sunshine that ideal for conversation into solar energy. The county's proximity to the capital, Nairobi, as well as location of the county in the Kenyan highlands was convenient for the research as the county provided samples from both rural and urban areas (Gitone, 2014).

Sampling design and sample size

Figure 3; Map of the Sample Unit distribution



The study applied both qualitative and quantitative research approaches to examine environmental impacts of household solar energy use adoption in Murang'a County to allow for analysis, drawing of conclusions and giving recommendations with a basis of the study (Creswell, 2009). The households were clustered into constituencies first and constituencies randomly selected according to their geographical location in the county. Local administration and community volunteers were used to obtain the different areas' population data to constitute the sampling frame.

Out of the seven (7) constituencies in Murang'a County, four (4) constituencies were used to conduct the study and Cochran formula was used to calculate the sample size ultimately obtaining a sample size of 384 households. According to Bostley and Peters (2023), the Cochran formula is used when the research parameters are the proportion and for a large population like that of Murang'a County. The formula aids researchers in getting a sample size having a desired confidence level, precision level and population proportion estimates. The Cochran formula is:

$$n = \frac{z^2}{4e^2} \qquad n = \frac{(1.96)^2}{4(0.05)^2} = 384.16$$

n = sample size p = the population proportions
e = acceptable sampling error (e = 0.05)

z = z value at reliability level or significance level.

Reliability level 95% or significance level 0.05; z = 1.96

Reliability level 99% or significance level 0.01; z = 2.58

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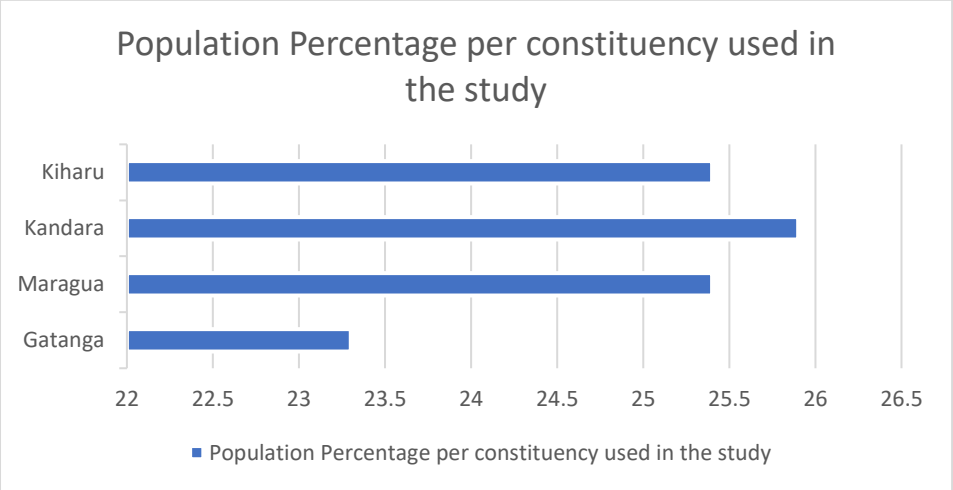
Figure 4; Study population distribution per constituency



Both female and male members of the households were interviewed depending on whom the researchers found in each household during the study. Observation and interview schedules were the main research primary data collection methods with questionnaires applied for most parts of the sample unit. The researcher through observation obtained data on a number of households in each compound, use of the solar PV and the installation processes of solar PV. For triangulation purposes, peer-reviewed publications, journals, books, articles and the internet were used to gather secondary data.

Data processing and statistical analysis

Population data from the Kenya National Bureau of Statistics (KNBS) was used to determine the total population in Murang'a County and serve as a percentile base for the study population. Data collected was analyzed using SPSS software, STATA and R software having a 95% confidence level ($p<0.05$) after being extrapolated and organized in Microsoft Excel. Narrative and thematic data analysis techniques were applied to analyze key indicators of the study.

Ethical considerations

The researcher obtained a research permit from the National Commission for Science, Technology & Innovation, Kenya, and the study followed the ethical guidelines therein stipulated which later informed the consent obtained from the household owner. Study participants voluntarily participated in the study and their anonymity was respected throughout the study. Research assistants were briefed on matters of voluntary participation, participants' anonymity and etiquette & professionalism by following the principles of ethical research.

FINDINGS AND DISCUSSIONS

Of the study population who had adopted solar energy use as the main source of energy in their households in Murang'a County, solar PV was the main SET applied. While most households still use hydropower as a source of lighting and firewood or liquid purified gases (LPG), adoption of renewable energy sources has been steadily improving with findings establishing that 4.7% of the population used bio-energy for their energy needs, 51.4% used hydro-energy, 1% used wine-energy and 22.5% used solar energy. This was against an equally substantive section of the population that still used sources from fossil fuels like 22.6% who used kerosene, 3.9% who used diesel, and 24.3% who used charcoal and a high number of 47% who used firewood whose main sources was through cutting of trees.

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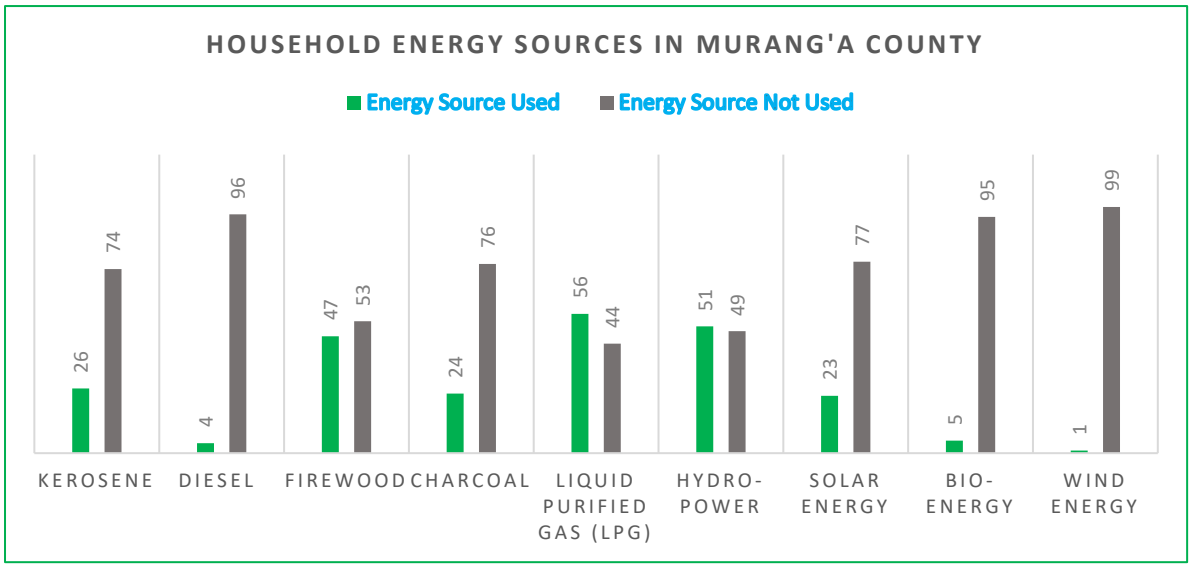
Figure 5; Murang'a County's household energy sources



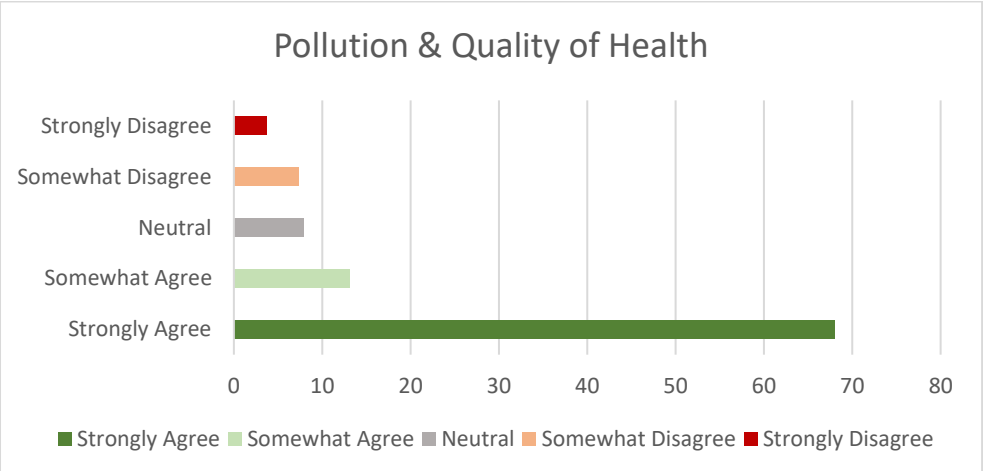
Environmental impacts of household solar energy use adoption in Murang'a County

Reduce pollution & Improve quality of health

Most of the study population Murang'a County, at 68%, strongly agreed that adoption of solar energy use subsequently led to prevention of toxic gases reducing pollution and improving the quality of health while 13.1% of the study population somewhat agreed. Of the study population 7.3% somewhat disagreed that adopting solar energy use led to prevention of toxic gases and thus reduced pollution and improved quality of health. However, 3.7% strongly disagreed with this, 7.9% of the study population were neutral, and neither agreed nor disagreed as they mainly lacked knowledge of prevention of toxic gas emission being an advantage of solar energy use adoption or had not adopted solar in their households.

Of the 68% of the study population that strongly agreed that adoption of solar energy use subsequently led to prevention of toxic gases reducing pollution and improving the quality of health 36% had adopted solar energy use in their households with most of the 64% who had not adopted citing financial constraints as the main reason for having not adopted. Although 3.7% of the population strongly disagreed that adoption of solar energy use led to prevention of toxic gases reducing pollution and improving the quality of health, more than 34% of them had adopted solar energy use in their households citing energy reliability as the main reason of adoption.

Figure 6; Solar energy use reduces pollution & improves quality of health



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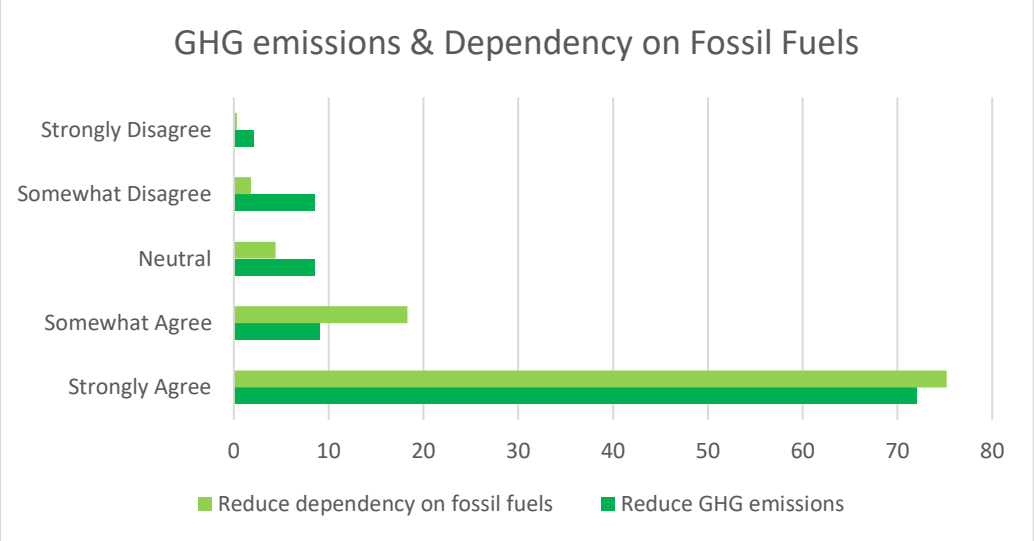
Cox (2016) states that toxic gases cause air pollution that is a hazard to health. Use of fossil fuels such as wood fuels, kerosene and diesel causes toxic gas emissions that have the potential to negatively impact health and the environment by contributing to climate change. The World Economic Forum's 15th global risk report prepared in 2020 lays out several effects of toxic gas emissions which include natural disasters, health hazards that cause loss of life or health deterioration as well as ecosystem stress. A great alternative to sources of these toxic gases is solar energy whose great potential to reduce toxic gases emissions directly improves health and reduce negative environmental effects through pollution (IRENA, 2019).

Reduce GHG emissions & Reduce dependency on fossil fuels

While 8.5% and 2.1% of the study population in Murang'a County somewhat agreed and strongly disagreed respectively that solar energy use adoption reduces GHG emissions into the atmosphere, 72% strongly agreed and 9.0% somewhat agreed. Despite the high number of the study population that believed that adoption of solar energy use led to a reduction in GHG emissions, 8.5% of the study population neither agreed nor disagreed. 75.2% of the study population strongly believed that solar energy use adoption can positively impact the environment through reduced use of fossil fuels with only 2.1% of the study population strongly disagreeing. 96% of the 2.1% of the study population who strongly disagreed that solar energy use adoption reduces GHG emissions into the atmosphere, had adopted solar energy use in their households with 47% of the population who strongly agreed that solar energy use adoption reduces GHG emissions into the atmosphere having adopted solar energy use in their households.

Figure 7; Solar energy use reduces GHG emissions & dependency on fossil fuels



Williams *et al.*, (2012) and the Kyoto Protocol argue that greenhouses gases (GHG) are defined as methane (CH_4), fluorinated gases like hydrofluorocarbons (HFC_S), carbon dioxide (CO_2), sulfur hexafluoride (SF_6), nitrous oxide (N_2O) and perfluorocarbons (PFC_S). According to the UNEP (2019) Emission Gap Report, emission of fossil fuels worldwide in 2018 was an equivalent of 55.3 $GtCO_{2e}$ out of which CO_2 emissions amounted to 37.5 $GtCO_{2e,}$ more than half of the total GHG emissions. High-energy demand both in industries and in household is the main driver of fossil fuels' emissions resulting to climate change. Through the Kyoto Protocol countries are expected to reduce dependency on fossil fuels and this has seen both developed and developing countries transition to renewable energy sources like solar energy. This has seen an increment in solar energy use globally by approximately 31% (Omer, 2012).

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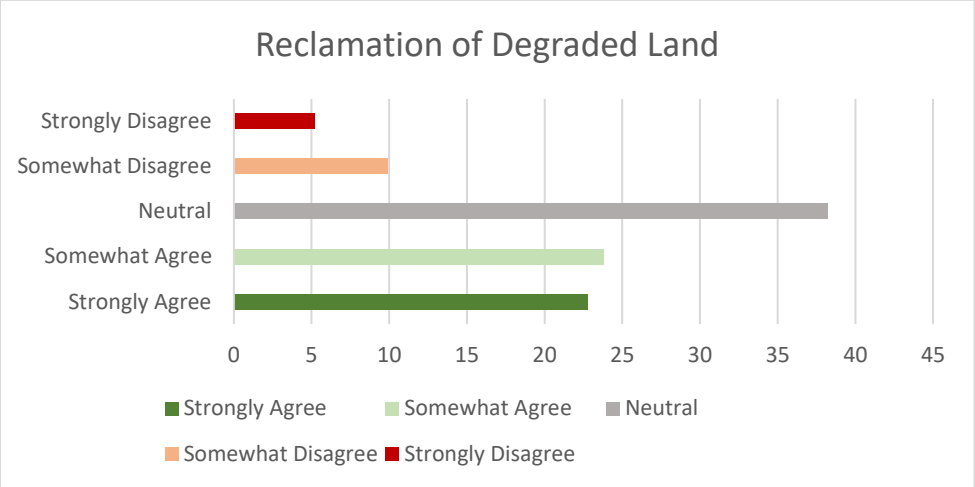
Reclamation of degraded land

In Murang'a County, most of the AMLs are because of quarrying activities that are viewed as one of the main environmental pollutants in the county. Quarrying is practiced in most parts of the lower regions in the county that include building blocks & ballast excavation, harvesting of sand, and brick and soil extraction for use in making bricks and pottery. While there is scanty information on these quarrying activities in Murang'a County, it is approximated that in a year the quarries harvest an estimated 42,900 tonnes of sand, 189,770 tonnes of hard core and 22,016 tonnes of ballast. These mining activities are estimated to have employed over 7,000 people directly and indirectly (Murang'a CIDP, 2018).

Research established that while the leadership in Murang'a county has not put efforts towards using solar energy in reclaiming degraded land the study population was in support of the same but 38.2% of the population did not understand this and were neither in agreement or disagreement on solar energy's use in reclamation of degraded land. Only less than a quarter of the study population, 22.8% strongly agreed that solar energy use adoption would positively impact efforts of reclamation of degraded land in the county with 23.8% somewhat agreeing. Of the 22.8% who strongly agreed, 87% had adopted solar energy use in their households with only 11% of the 5.2% of the population who strongly disagreed having adopted solar energy use in their households.

Figure 8; solar energy use helps in reclamation of degraded land



Abandoned mine lands (AMLs) include areas affected by or adjacent to mines but mainly the abandoned mines. In most countries, AMLs remain abandoned, exposed and idle without any consideration for reuse as they're mainly located in areas not suitable for either industrial or commercial development or residential use. While AMLs may appear not to hold any significant advantage after mining activities are done, they may very good sites for local renewable energy sources towards generation of electricity from sources like wind through installation of wind turbines or through solar by installation of photovoltaic power plants. This would result in an increase in energy efficiency but more importantly reduce the land generation impact on the environment through enhancing diversity of energy at the same time returning the AMLs to productive lands. In Espenhain, Germany, a former lignite mine ash deposit was converted into a 5-MW PV power plant with approximately 33,500 solar modules generating electricity directly to the electricity grid in Germany and has been in operation since 2004 (US-EPA, 2011).

Improve quality of water resources

Most of the water in Murang'a County is sourced from springs, shallow wells, rivers, boreholes and rainwater harvesting from roofs. These sources supply approximately 60% of the population with clean water. The county has 27 water supply and treatment plants and 16 irrigation schemes all of

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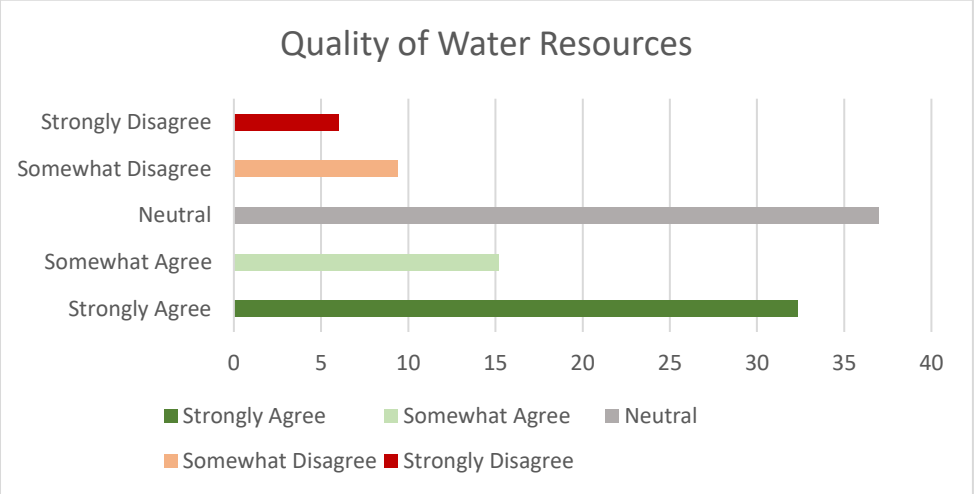
which do not use solar energy but utilize both fossil fuels like diesel and hydropower. While the county enjoys abundant water resources treatment of water from these sources is sometimes not available and have also being polluted over the years due to discharge of wastewater from both households and industries (Murang'a CIDP, 2018).

32.3% of the study population strongly agreed that solar energy use adoption can positively impact the environment through improvement of quality of water resources with 61% of this population having adopted solar energy use in their households. 37% of the population however, neither agreed nor disagreed mainly due to lack of knowledge on this environmental impact of solar energy use adoption. Only 6% of the study population strongly disagreed that solar energy use adoption can positively impact the environment through improvement of quality of water resources with 36% having adopted solar energy use within their households citing energy reliance as main reason of adoption.

Figure 9; Solar energy use improves quality of water resources



According to UN (2020), water scarcity is a major challenge for most countries worldwide due to effects of climate change, is increasingly worsening with increased energy demand from economic growth and population rise in both developed, and developing countries like Kenya. Discharge of water effluent from households without treatment results in pollution of fresh water sources and aggravated an already dire problem. The United Nations Environmental Program (UNEP) estimates that 1/3 of the global population currently live in countries that are water stressed and 2/3 of the population in the world will face water scarcity by 2025. Water resources can be improved and sustainable water supply achieved but energy requirements for water treatment processes need to be considered. Most of the world experiences abundant solar radiation that can be converted into solar energy and used in desalination of both brackish and seawater to provide fresh water for water-stressed regions. In treating wastewater using solar energy, the common technologies applied are solar disinfection, solar photo catalysis, solar detoxification, solar desalination and solar pasteurization. For treating household wastewater, solar desalination and solar distillation technologies can be adopted to purify brackish water into usable/potable water (Ying Z. et al, 2018).

Improve food security

While most of the study population had not adopted solar energy for Smart Farming, 33.6% strongly agreed that solar energy use could positively impact the environment and result in improved food security. Of this population, 67.1% had adopted solar energy use in their households.21.8% neither agreed nor disagreed mainly due to lack of training and knowledge on the same. less than a quarter of the study

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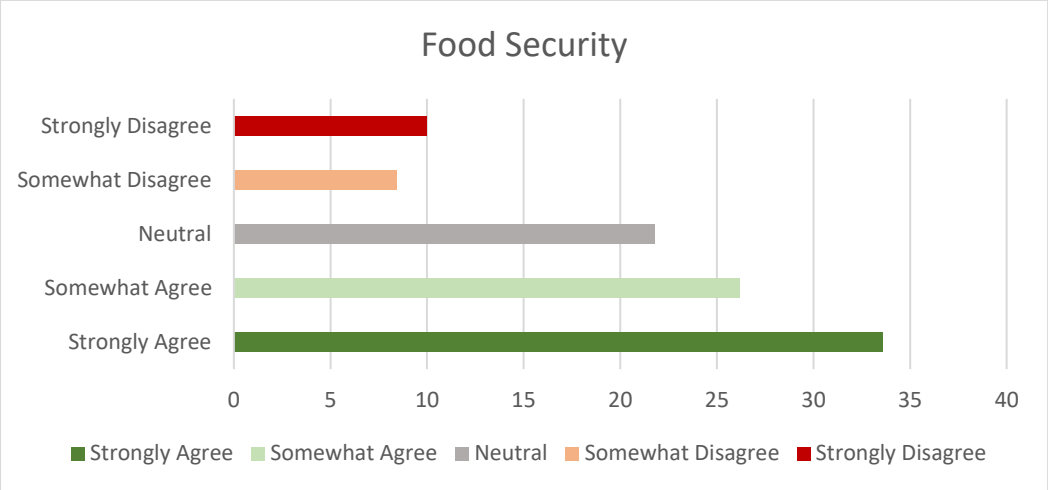
population at 10% strongly disagreed that solar energy use could positively impact the environment and result in improved food security with more than 90% of them having not adopted solar energy use in their households.

Figure 10; Solar energy use improves food security



Mohammad (2019) argues that various environmental issues especially climate change heavily impact on food security worldwide. In Africa, this directly affects human existence through changes in rainfall patterns, higher temperatures, flooding and droughts and extreme weather with direct impacts like unsustainable agricultural practices, rising sea levels, increased diseases and unsustainable water supply also being experienced. Agricultural activities ensure food security worldwide and have over the years been negatively affected by climate change. In the face of environmental hazards caused by climate change measures like Climate Smart Agriculture can be adopted to ensure food security by helping farmers enhance the quantity and quality of goods to efficiency that is optimal. Solar power can be applied in Climate Smart Agriculture with one of its biggest advantages being giving farmers the ability to monitor remote fields and farms and collect farm data like moisture and temperature conditions that help them better care for their crops and livestock. Solar energy can also be used to supply energy for irrigation systems by providing an affordable, reliable clean and flexible energy source with a great potential to reduce irrigation costs thus reducing production costs and subsequent costs of goods to consumers (Jonathan et al., 2018)

CONCLUSION AND RECOMMENDATIONS

The study faced a few limitations with the main limitation being lack of adequate financial resources, which prolonged the data collection period. Language barrier was also encountered as some of the research assistants could not speak the native language, Kikuyu, spoken by members of most households. The researcher also encountered hostility in some areas with some of the population assuming the researcher was a government official collecting private data. The hostility was however significantly reduced once the researcher provided necessary documentation for research with most of the hostile population becoming quite apologetic and helpful.

The study confirmed that most of the population in Murang'a County is still dependent on fossil fuels as their sources of energy and therefore continue to negatively impact the environment. With a growing population, more people continue to demand for energy. The rising global energy prices coupled with financing challenges in installation of clean energy like solar energy continue to increase this demand for fossil fuels like firewood and charcoal the leads to deforestation. The study poses a challenge for environmental protection through technology

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innovations and incentives and optimization of the energy structures in the county.

The study also corroborated previous research that solar energy use adoption is indeed very low with less than a quarter of the study household/ population having adopted solar energy. While effects of using non-renewable energy worldwide and in the county continue to be felt through climate change that has negatively affected the environment, adopting renewable energy option could indeed go a long way into alleviating these effects. This research established there was indeed a correlation between solar energy use adoption and the environment through adoption of solar energy use in the county's households and confirmed that indeed the environment can be impacted positively and conserved through solar energy use.

For most of the study population in Murang'a County, lack of knowledge on solar energy use adoption or its positive effects on the environment was the main reason that most of the study population could not confidently relate to various positive impacts of solar energy use adoption in the county. Over 20% of the study population had adopted solar energy use primarily due to unavailability of the national hydropower grid or due to unreliability and high costs of using other energy sources. In spite of most of the study population's primary reason of adoption not being conservation of the environment, more than a quarter strongly agreed that solar power positively impacted the environment through various interventions and the uptake should be encouraged.

While the study population strongly agreed that solar energy use adoption positively influenced the environment, the lack of knowledge for most of the population could be resolved through formal and informal sources of training by both government and the private sector. Formal education and field trainings could be used to increase knowledge on positive impacts of solar energy use thus increasing level of uptake. Whereas the study confirmed the hypothesis that solar energy use indeed had positive impacts on the environment, efforts are needed to improve the county's population's knowledge on solar energy use and its direct positive impact on the environment. Part of the study population that understood the positive impacts of solar energy use to the environment but had not adopted cited high costs of installation as a hindrance.

Financial initiatives to increase uptake could be considered to sensitize the population and aid in initial installation costs that can be very high for PV technologies. Financial initiatives that could be applied towards improved uptake of solar energy use in households in the county are among others;

- Funding sensitization campaigns and training activities on the importance of solar energy use adoption in the county.
- Resource mobilization through public-private partnerships (PPPs) allocation towards PV technology acquisition.
- Support on maintenance of the SET sustainability among households that have adopted to encourage long-term use and more adoption of the SETs.

DECLARATION

Authors contribution statement

Pauline N. Mutura: Conceived the study; Carried out field data collection; Analyzed and interpreted the data; Wrote the paper.

Dr. Peter Kamau & Dr. Christine Majale: Guided the study and paper writing; Improved the paper through reviews; Offered invaluable insights during both the field data collection and paper writing; Wrote the paper

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Data availability statement

Data will be made available on request.

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Declaration of interest statement

The authors declare no conflict of interest.

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