

ASSESSING THE NEXUS OF CO₂ EMISSIONS & RENEWABLE ENERGY -
IMPLICATIONS FOR SMALL SCALE PRIVATE INDUSTRY: A CASE STUDY OF
ECOTOURISM IN MACHAKOS COUNTY, KENYA

A Project Paper

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By

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ABSTRACT

As the world works towards curbing carbon emissions, promoting investment in renewable energy development within tourism can accelerate the clean energy transition. With a pledge to achieve 100% renewable energy use by 2050, Kenya has been one of the leaders in making the transition to clean energy within sub-Saharan Africa. At the same time, Kenya is the largest tourist destination in sub-Saharan Africa. This paper will explore how Kenya's tourism industry can reduce greenhouse gases through transitioning to renewable energy. A literature review provides an analysis of the current solar energy portfolio in Kenya, policies surrounding tourism, and renewable energy development. The causal relationship between CO₂ emissions, tourism, renewable energy, and gross domestic product (GDP) will be examined through the deployment of an autoregressive distributed lag model. A case study of three Machakos County enterprises will be presented, examining the economic, social, and environmental impacts of the development of private systems. Interviews with companies in the tourism sector on the benefits and challenges to transitioning to cleaner energy sources will be discussed. Policies, subsidies, and other external factors will be considered. This research will be focused on the question: *How can the tourism sector in Kenya reduce their carbon footprint through renewable energy?* Finally, recommendations will be made on how to further increase renewable energy adoption in the tourism sector. A set of policy recommendations will be developed.

BIOGRAPHICAL SKETCH

Homari Aoki received her Bachelor of Science in Environmental Economics and Policy and Bachelor of Arts in Portuguese from the University of Illinois at Urbana-Champaign. During her studies, she spent three semesters in Brazil. She went on to serve two years as an Agriculture Volunteer for Peace Corps in Cameroon where she focused on sustainable agriculture production, integrating rabbit rearing and beekeeping into existing farming practices. Upon return to the United States, she began her work at the Bureau of Safety and Environmental Enforcement (BSEE) under the Oil Spill Preparedness Division. Her interactions with offshore wind development at the BSEE along with her international experience motivated her to enroll in the Master of Professional Studies Program for Global Development at Cornell University to deepen her understanding of international energy development.

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LIST OF ABBREVIATIONS

ADB	African Development Bank
AIC	Akaike Information Criterion
ARDL	Autoregressive Distributed Lag
ATV	All-Terrain Vehicle
BSEE	Bureau of Safety and Environmental Enforcement
BTU	British Thermal Unit
COVID-19	Coronavirus Disease 2019
ECM	Error Correction Model
ECT	Error Correction Term
EIA	Energy Information Administration
EPRA	Energy and Petroleum Regulatory Authority
ESMAP	Energy Sector Management Assistance Program
GoK	Government of Kenya
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GW	Gigawatts
ILO	International Labor Organization
IOSH	Institution of Occupational Safety and Health
IRB	Institutional Review Board
KNBS	Kenya National Bureau of Statistics
KNES	Kenya National Electrification Strategy
KNEMA	Kenyan National Environment Management Authority
KOSAP	Kenyan Off-grid Solar Access Project
KPLC	Kenya Power Lighting Company
Ksh	Kenyan Shillings
LMCP	Last Mile Connectivity Project
MoE	Ministry of Energy
MtCO ₂ E	Metric tons of Carbon Dioxide Equivalent
MW	Megawatts
NGO	Non-governmental Organization
PAYG	Pay-As-You-Go
PI	Principal Investigator
PV	Photovoltaics
SDGs	Sustainable Development Goals
SHS	Solar Home System
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
UNWTO	United Nations World Tourism Organization
USAID	United States Agency for International Development

USD	United States Dollar
W	Watts
WEEK	Women in Energy Enterprise in Kenya
WTTC	World Travel & Tourism Council

CHAPTER 1: INTRODUCTION

1.1 Introduction

In 2016, world leaders adopted the 17 United Nations (UN) Sustainable Development Goals (SDGs) through the 2030 Agenda on Sustainable Development to “promote prosperity while protecting the planet” (*Home - United Nations Sustainable Development*, n.d.). These goals provide a blueprint to address global challenges faced by the international community. Such challenges include poverty, inequality, climate change, environmental degradation, peace and justice (UN SDG, n.d.). The SDGs call on every country to work towards common goals regardless of the economic status. Of these, goals 7 and 8 focus on a just transition to affordable clean energy, and decent work and economic growth, respectively. To promote economic growth, private industry must ensure a just energy transition and development must be designed with disparities between different populations in mind (UN, 2021).

Building on these two SDGs, a balance between the economic growth of emerging economies and reduction in carbon emissions is essential to a sustainable future. Tourism, one of the largest industries in the world, makes important contributions to the economies of developing nations (United Nations Environment Programme, 1997). According to the United Nations World Tourism Organization (UNWTO), this industry has seen a dramatic boom in recent years. International tourist arrivals have increase 56-fold over the past 68 years as noted in Figure 1 (UNWTO, 2017). The tourism industry is expected to continuously grow as more people attain disposable income. CO₂ emissions, within the industry, remain a major challenge in the sector’s commitment to reducing its climate-related impact. One method of reducing tourism-related CO₂

emissions is through the replacement of non-renewable electricity sources used within the industry, with renewable energy technology and promotion of ecotourism.

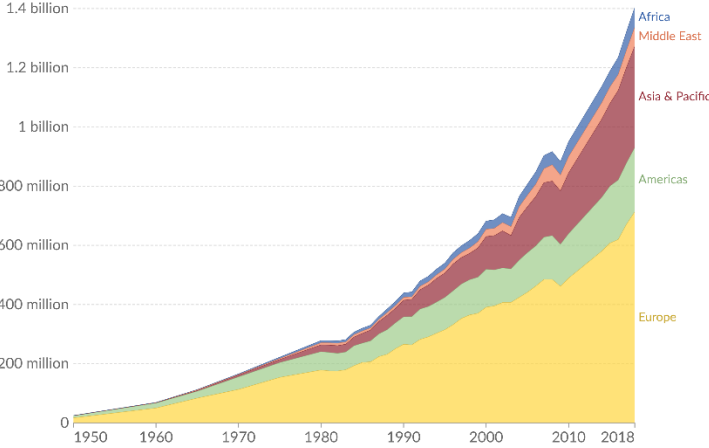


Figure 1: International Tourist Arrivals Per Year by Region
Source: UNWTO (2019)

1.2 Country Context

Situated on the equator, Kenya is the second largest country in East Africa. With over 53.77 million people, the country’s population has grown rapidly with an average annual growth rate of 2.5% in the past 10 years (World Bank, 2019). Major languages spoken include Swahili and English, though there are a total of close to 70 languages spoken in Kenya. Kenya is currently one of the leading tourist destinations in the region (Hastings, 2020). World famous safari parks, cultural heritage, and coastal beaches are among a few of the diverse tourist attractions available. Kenya’s main tourist attractions for international visitors are the vast national reserves (Kenya High Commission, n.d.), as illustrated in Figure 2. The annual wildebeest migration at the Maasai Mara, along with the humpback whale migration has made Kenya one of Africa’s leading tourist destinations (Kenya High Commission, n.d.). The United Nations Development Programme (UNDP) posits that at the same time, many environmental challenges such as

challenges to sustainable economic growth remain including COVID-19's economic disruptions, climate change, corruption, economic inequality, and security (Trade.gov, n.d.).

The key sectors that contribute to economic growth within Kenya are agriculture (25%), manufacturing (10%), and tourism (8%) (GoK, n.d.-b; Tourism Economics, n.d.). Tourism is the top foreign exchange earning industry in the country. In this respect, tourism can play a key role in the development of the economy and reduction of poverty (Medina-Munoz et al., 2014).

According to the Kenya National Bureau of Statistics (KNBS), currently, the tourism industry supplies 9% of the country's formal jobs providing employment to 1.6 million people (2020).

Tourism remains one of six priority target areas for economic development under Kenya's Vision 2030 long term development plan.

The Vision 2030 plan integrates three pillars including an Economic and Macro, Social, and Political components (GoK, n.d.-a). One of the eight Economic and Macro sectors focuses on tourism. This sector is then broken down into 17 different tourism sections including tourism of premium parks, resort cities and other tourism such as health and medical, and business and conference tourism (GoK, n.d.-a). Kenya's status, as an international hub for East Africa, will help develop the new sectors of tourism. As tourism development continues, it is essential to incorporate the impacts of climate change on the sector.

1.4 Current Energy Background

Access to Electricity

As one of the fastest countries to accelerate towards electrification in the past decade (World Bank, 2018), Kenya has also committed to a just transition to renewable energy. The Government of Kenya (GoK) has made two key commitments on this front. First, the Kenya National Electrification Strategy (KNES) was developed in 2018 to support the achievement of universal access to electricity to all citizens by 2022. Second, in support of the world targets, Kenya's president, Uhuru Kenyatta, pledged to reach a full transition to clean energy by 2030. These two commitments have fueled the push towards fast renewable energy development.

Currently, 2.3 gigawatts (GW) of energy capacity is installed in Kenya (EPRA, n.d.). Of this installed effective energy generation capacity, only 32.2% comes from oil with the rest coming from renewable energy (Takase et al., 2021a). Figure 3 shows that the provisional local electricity generation in Kenya, for 2021, was made up of hydropower (33%), geothermal (34%), thermal which includes all off grid power (16%), wind (13%), solar (3%), and co-generation (<1%) (KNBS, 2021). Approximately 30.3% of Kenyans still lack access to electricity (World Bank, n.d.-a). While Kenya has achieved substantial progress in increasing energy access, the residents who lack access live in areas that are difficult to reach with the national grid. Both private sectors and off-grid solutions will play a key role in providing electricity to these

marginalized residents. Where there is already access to energy, it is mostly generated through the abundant renewable energy sources such as wind, hydro, geothermal, and solar.

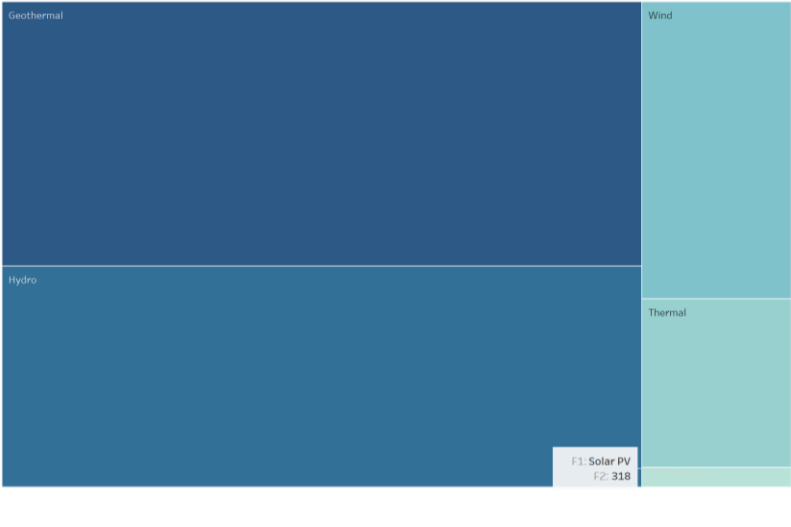


Figure 3: Installed Effective Capacity of Renewables in Kenya, 2020
Source: KNBS, 2021

The national electrical grid faces challenges with frequent rolling blackouts which disproportionately impact the poor (Maende & Alwanga, 2020). Due to these issues, most businesses and residents that can afford it supplement their energy needs with diesel backup generators on standby or have installed solar photovoltaic systems (Macharia, 2013).

CHAPTER 2: METHODS

2.1 Scope of Issue

Climate change has major potential consequences on the tourism industry which is strongly dependent on natural resources. There is a need to reduce environmental impacts of tourism and limit the CO₂ emissions produced within the industry. At the same time, the reliability of the energy must be addressed to increase the competitiveness of tourism in Kenya. Could private renewable energy development lead to an increase in sustainable tourism while simultaneously strengthening economic and social progress within Kenya? As stated earlier, this paper will evaluate the nexus between renewable energy, CO₂ emissions, and GDP. This research utilizes a literature review, econometric modeling, and case studies to identify the benefits and challenges of renewable energy development in Kenya's tourism industry.

2.2 Methods

2.2.1 Literature Review

A literature review was conducted to identify renewable energy systems utilized in the tourism industry in Kenya. This literature highlights valuable insight on existing data to build the rest of the paper. Causal relationships between renewable energy, tourism, and GDP in other countries will be examined to make general comparisons and understand past studies. Government policies and programs will be explored along with renewable energy programs developed by non-governmental organizations and private sector companies. Both passive and active renewable energy technologies, to help reduce the CO₂ emissions within the hoteling industry, will be

discussed. From my preliminary investigation, the literature review identifies possible variables that may affect the long-term sustainability of renewable energy adoption within the Kenyan tourism industry. A look at past programs will assist in the development of recommendations to increase the effectiveness of renewable energy programs within Kenya.

2.2.2 Autoregressive Distributed Lag Model (ARDL)

An econometric model will examine the interactions between renewable energy development, CO₂ emissions, gross domestic product, and tourism within Kenya. Data is taken from various sources including the World Bank, the Kenya National Bureau of Statistics (KNBS) and Energy Information Administration (EIA). Observations from the ARDL model will be reviewed as well as policy implications derived from the model. An ARDL model was used to understand the differences between the long run and short run relationships. This approach is appropriate for studies with small samples (Pesaran & Shin, 1995).

2.2.3 Case Studies

Three case studies of ecotourism-related companies, from the Machakos region of Kenya, were developed to understand the specific opportunities and challenges within the industry. While these three companies are not fully classified as ecotourism companies, their efforts to build both environmental and cultural awareness, and generate financial benefits for the local people and private industry follow ecotourism principles. Due to travel restrictions imposed for COVID-19 safety measures, the three tourism companies chosen, Vota Ranch, Lukenya Motorcross, and Lukenya Resort, were based on their previous connections to Cornell University faculty.

Institutional Review Board (IRB) approval was provided by Cornell University to conduct interviews with the three tourism companies in January and February 2022. All three tourism companies provided letters of support to de-identify their businesses for the purpose of this report. A Cornell faculty member, who was present in Kenya, traveled to each company along with a hired researcher/transcriber who helped facilitate the interviews in-person. When possible, a hybrid in-person/virtual format was set up to allow the Principal Investigator (PI) to attend the interviews without traveling to Kenya. Video conferencing was utilized to allow the PI to attend the interviews. Owners, managers, and employees with specialized functions were interviewed separately, while other employees and clients were interviewed together. In total, 24 people were interviewed using in-depth interviews and focus group format. Interviews lasted between thirty minutes to one hour and were held in English as well as Swahili and Kamba. The portions of the interviews that were held in Swahili and Kamba were transcribed and translated into English. Atlas.ti software was used to analyze the interviews. The case study approach was used to gain greater understanding on specific cases and highlight the challenges and opportunities different companies face (Crowe et al., 2011). The case studies aim to apply concepts taken from the literature review and econometric modeling to three private tourism companies.

CHAPTER 3: LITERATURE REVIEW

3.1 Renewable Energy Development in Kenya

Abundant renewable energy resources are available in Kenya. Of the renewable energy sources, hydroelectric and geothermal power make up 80% of the energy generation mix (Clean Technica, 2021). Table 1 reveals that while the country relies heavily on renewable energy, renewable sources are still underexploited. An increase in the utilization could further mitigate greenhouse gas emissions (GHGs) and reduce negative environmental impacts of non-renewables. The Kenyan National Environment Management Authority (KNEMA) estimates that by 2030, geothermal energy alone could yield a reduction of 14 metric tons of carbon dioxide equivalent (MtCO₂e) in GHGs (GoK, 2018). Wind and solar could deliver smaller yet still sizeable abatements of 1.4 and 1.0 MtCO₂e, respectively (GoK, 2018). In Kenya, current renewable energy development relies heavily on foreign investment from non-government organizations (NGOs), world governments, and private industry. The Kipeto Wind Farm and Lake Turkana Wind Power projects were sponsored by the United States Agency for International Development (USAID).

Table 1: Renewable Energy Potential and Installed Capacity by Source

	Estimated Potential	Installed Energy Capacity
Geothermal	7,000 – 10,000 MW	828.04 MW
Hydro	3,000 MW	856.23
Bioenergy	1,000 MW	2 MW
Solar Energy	15,000 MW	52.MW
Wind Energy	Unknown	336.05 MW
Tidal Energy	Unknown	Unknown

3.2 Energy Systems in Kenya

Decentralized power generation systems provide increased energy access by allowing households to purchase their own systems. These systems vary in capacity and in cost from products that power just one device to more complex systems that can power an entire household or business. These systems, as illustrated in Figure 4, are tailored to the income levels and the energy usage capacities of the household (Opiyo, 2020). Many companies offer pay-as-you go (PAYG) services which allows for financial inclusion. PAYG is a financial mechanism that originated in Kenya (Sanyal et al., n.d.). This system encourages the immediate access to solar photovoltaic (PV) panels and associated equipment for low-income customers. It uses a mobile phone-based transfer system to enable remote activation of the equipment (Sanyal et al., n.d.). Payments are made in installments over a longer period. The device is “locked” if payments are stalled but can be “unlocked” through payment.

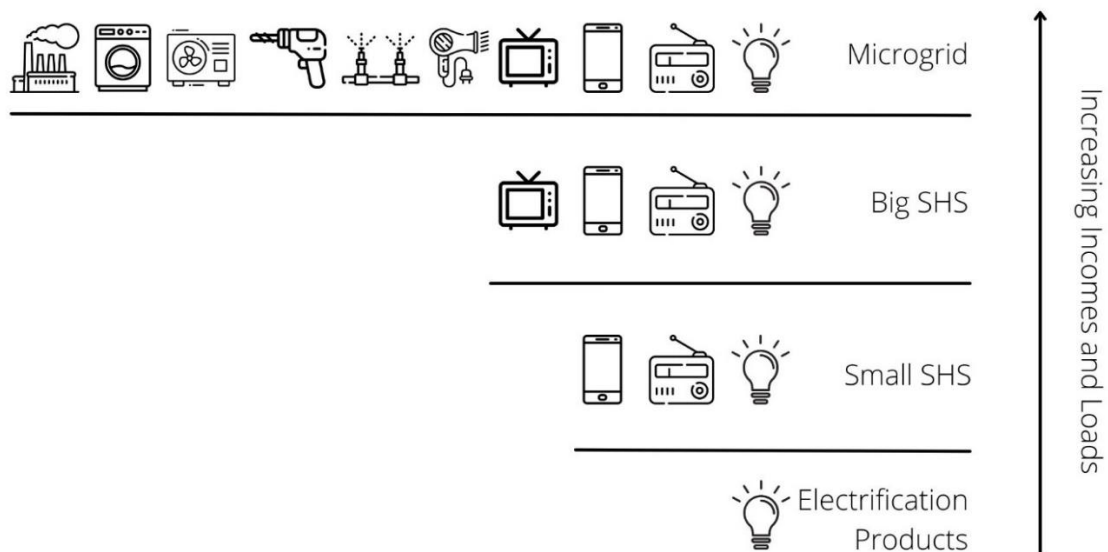


Figure 4: Energy Ladder
Adapted from Opiyo, 2020

The potential solar energy generation for Kenya is remarkably high due to the country’s proximity to the equator (Figure 5). According to Energy and Petroleum Regulatory Authority (EPRA), the total estimated solar potential in Kenya is almost 15 gigawatts (GW). However, solar energy only makes up 1% of the current energy mix (EPRA, n.d.). Current installed solar energy capacity equals 52.0 megawatts (MW). This makes the cost of solar PV generation extremely competitive compared to other energy sources. In a shift during the past decade, solar PV has become the most economical option for renewable power generation in Kenya (Figure 6). This trend is projected to continue as geothermal and wind project’s costs are not expected to reach parity with solar PV in the future (Global Data, 2020).

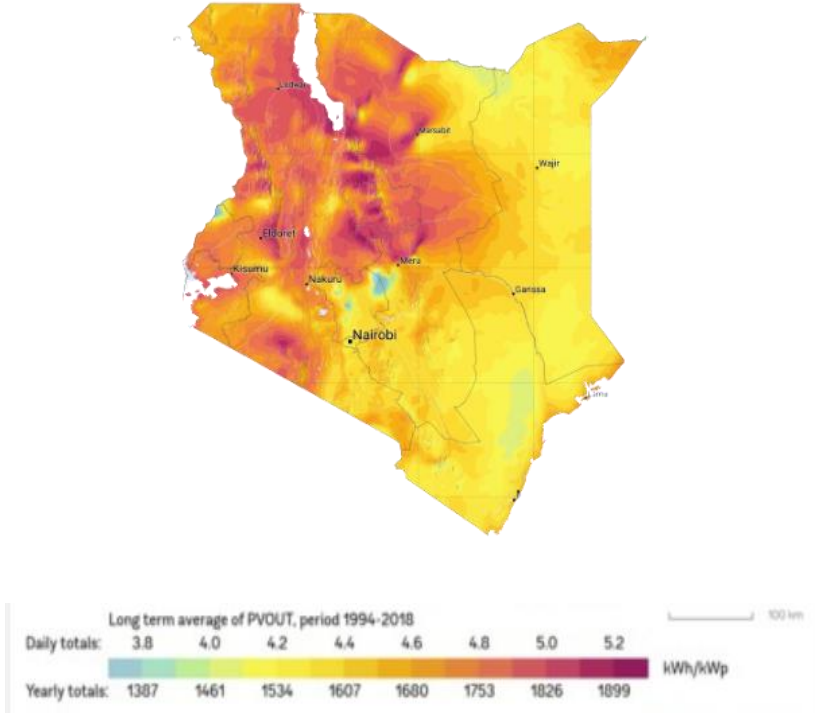


Figure 5: Solar Irradiance in Kenya 2020
 Source: Global Solar Atlas 2.0

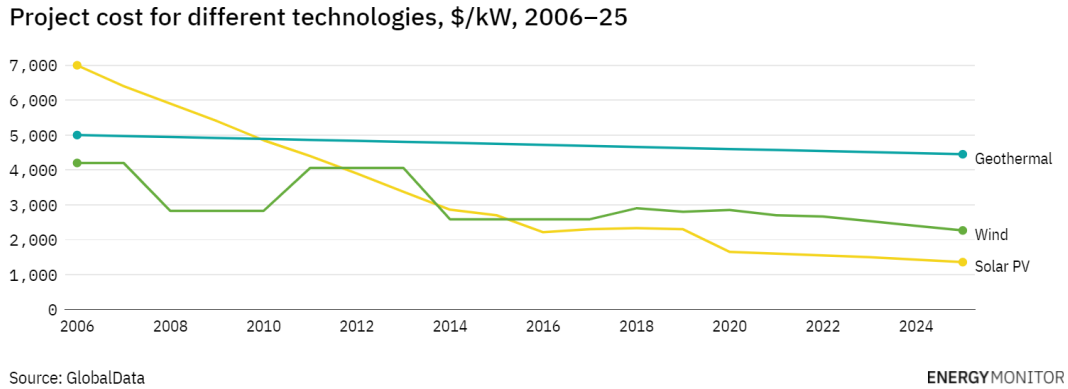


Figure 6: Cost of Renewable Energy Technologies 2006-2024
Source: Energy Monitor

3.2.1 Offgrid Solutions

Two main decentralized solutions exist for the development of solar energy: minigrids and solar home systems (SHS). Minigrids are small-scale energy generation and distribution networks that typically serve between 20 to 1,500 people (*Global Facility on Mini Grids / ESMAP*, n.d.).

SHSs, on the other hand, operate at the individual household level. According to the USAID and Power Africa, with an estimated ten million people using off-grid solar products, Kenya is the largest off-grid solar product market (“A Thriving Off-Grid Market – With a New Focus on Underserved Areas,” n.d.). Off-grid solar options are recognized by the Government of Kenya as pillars of electrification. Both play a critical role in reaching communities and individuals where electricity usage is expected to remain relatively low.

Minigrids provide a connection to multiple users much like the national grid. However, they operate at a smaller scale, often at the community level. Minigrids comprise a small-scale electricity generator, a power inverter, and a distribution network that connects to a localized group of consumers. An energy storage system could be a battery that provides a buffer for power supply and demand fluctuations. The power generation for minigrids is not limited to

renewable energy options such as solar, wind, and hydro; they can also be powered by diesel and other fossil fuels. Since solar and wind energy sources are dependent on weather, they are often not always reliable sources without battery storage (Lovins & Ramana, 2021). Two strategies can be used to increase the reliability of minigrids: combining energy generation sources together or increasing battery storage capacities. Due to the relatively high cost of current battery technology, the prevalent method in Kenya for increasing minigrid reliability is to combine solar PV with a backup diesel generator (NewClimate Institute, 2020). Enough energy generation can be provided by minigrids to power entire industries and drive economic growth. They can simultaneously connect to hundreds of individual homes, schools, hospitals, and power other income generating activities.

SHSs are much smaller in scope: they only power individual homes and range between 5 watts (W) to >100W (Winther et al., 2018). SHS are stand-alone systems that provide limited power generation from solar PV and include a small battery to allow for nighttime electricity. In Kenya, these systems are typically sold as a bundle with compatible products such as lamps, lights, phone charging kits, televisions, or refrigerators (*About - M-KOPA*, 2020). SHSs are considered the most reliable than minigrids and the national grid due to the limited infrastructure needed. However, they require replacement every two to four years (Opiyo, 2020). The SHS industry fails to address problems with e-waste generation (Cross & Murray, 2018).

Over the past decade, the cost of minigrids technology has been rapidly declining, with costs of solar hybrid minigrids estimated at USD \$0.49-0.68/kWh (Ksh. 57- 79/kWh) (*State of the Global Mini-Grids Market Report 2020*, n.d.). These minigrids can reach people who would not have otherwise gained access to electricity like women. As women's empowerment is most needed in

rural areas, many of whom live far from the national grid. In Kenya, where the cost of national grid extension is relatively high at USD \$1,047 (Ksh. 121,557) per household installation, and the average household consumption is relatively low at 380 kWh/year, the time for revenue to exceed grid extension costs is 22 years (*State of the Global Mini-Grids Market Report 2020*, n.d.). This can push the cost of grid extension up to USD \$1/kWh (Ksh. 116/kWh), making minigrids competitive in many places despite the higher costs of initial installation. In rural areas, where there is not enough demand, extending the national grid is not profitable and therefore will not occur. These are the regions where off-grid options can excel as cost-effective solutions that can provide sustainable energy. While this may be the case, the cost of connecting to a minigrid can still be prohibitively expensive for rural Kenyans.

SHSs can cost more per energy generation output but have been made affordable through asset financing systems. SHSs can range in cost, with the most basic systems priced around USD \$240 (Ksh. 27,864) (Adwek et al., 2020). Often a PAYG system is utilized to allow unbanked customers to pay for the cost of their SHS via mobile cash transfers. These mobile payments unlock access to the electricity based on usage or time. Once a predetermined payment period is complete (usually around 1-2 years), the SHS is unlocked and free to use for the duration of its lifetime. It should be noted there are government programs that can help subsidize the cost of both national grid extensions and off grid power projects. The Last Mile Connectivity Program (LMCP) is a program developed jointly by the Kenyan Government and the African Development Bank (ADB) that heavily subsidizes the cost of connection to the national grid. The Kenya Off-grid Solar Access Project (KOSAP), a program developed jointly by the Kenyan Government and the World Bank, similarly subsidizes off-grid solar energy projects (World Bank, n.d.-b).

The following is a chart (Figure 7) that shows the space in which minigrids are most cost effective per the size of a given community, as compared to other energy supply strategies. As shown, minigrids tend to excel in communities that are medium to smaller sized, medium to less dense, further from the national grid, comprise of complex terrain, and have weaker economic strength relative to other communities.

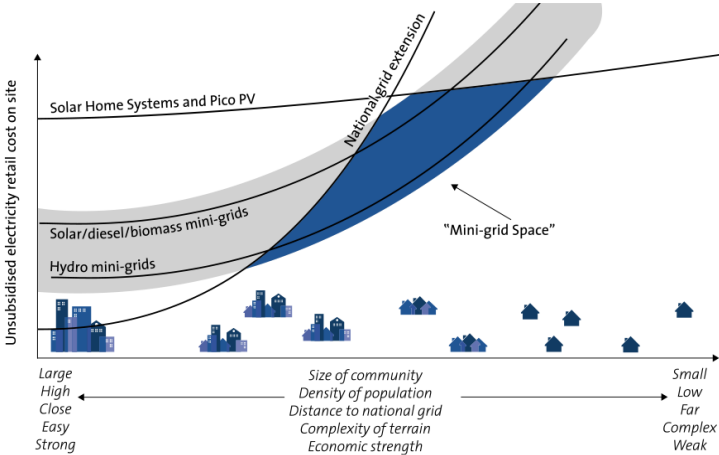


Figure 7: Minigrid Operating Space
 Source: EU Energy Initiative Partnership Dialogue Facility (2014)

Both minigrids and the national grid create around 15 to 28 jobs per 1 MW increase of energy capacity (New Climate Institute, 2021). While the national grid must comply with national mandated gender ratios for its employees, jobs are concentrated away from the communities they serve. Women benefit from national grid development but if our aim is to focus on the most marginalized, women in rural communities must be empowered. Both minigrids and SHS do not have requirements for gendered employment, however, they both create more local jobs. Minigrid and SHS development projects can be tailored to include gender-sensitive planning. There are examples of where women are the primary target audience of the jobs created (Dutta, n.d.; Hellqvist, 2021; Winther et al., 2017; World Bank, n.d.-d). Minigrids differ from SHS in

that they create jobs in local construction, operations, and management while SHS employ local sellers who act as technicians.

Communities connected to the national grid that do not have a local technician may suffer from delays to issues with the connection. Additionally, due to the aging infrastructure of the national grid, reliability of its electricity tends to be lower than on minigrid systems; users connected to both systems tend to prefer the reliability of the minigrid. Minigrids can provide faster access to communities that are further from the national grid since they do not need to be connected to existing infrastructure. SHSs can provide even faster electricity connection.

Both the national grid and minigrids can integrate public infrastructure projects such as water pumps and public lighting into their development. In contrast, due to the nature of the SHS being stand-alone systems, they are unable to integrate these projects. However, it should be noted that communities can install stand-alone water pumps and public lighting separately. Because stand-alone systems are not connected to any systems, it is less efficient.

There are advantages and disadvantages to both off-grid energy generation systems. In Kenya, minigrids are typically less reliable than commonly used SHSs but SHSs are vastly less capable (UNIDO, 2021). For instance, most SHSs only provide limited electricity generation supporting capabilities such as lights, phone chargers, and mini fridges. SHS are more affordable due to available asset financing schemes but are more expensive than minigrids in the long run. The shorter lifespan of SHS causes them to be more disposable, generating more e-waste and as a result are worse for the environment in this respect (Adwek et al., 2020). Larger appliances cannot be powered through a SHS, but they can be powered by minigrids. Minigrids can also be

scaled up more easily and can be connected to the national grid (USAID, 2021). This type of potential expansion capability allows for future electricity development of the region.

3.3 Solar Energy Opportunities in Tourism

The tourism industry can utilize off grid energy systems to generate energy for their numerous energy consuming activities. On top of the decentralized solar panels, other solar energy generation systems can be incorporated into their energy system. Both passive and active solar technology can be integrated to lower consumption of energy. The following section includes several solar energy technologies which could be deployed in Kenya.

3.3.1 Solar Water Heating Systems

Hot water can be supplied to hotels via a solar water heating system. These solar thermal systems may be a cost-effective method to heating hot water and pools. Still, in equatorial regions, the energy reduction in using these systems can be paid back in 2 to 4 years (Environment, 2017). Solar water heaters typically come in two types: flat plate collectors and evacuated tube collectors.

3.3.2 Flat Plate Collectors and Evacuated Tube Collectors

There are two main types of solar water heaters: flat plate collectors and evacuated tubes collectors. While flat plate collectors tend to be less costly, a closer look at the cost per British thermal unit (BTU) shows that evacuated tubes are more cost-efficient (Tiwari et al., 2016).

Flat plate collectors (Figure 8) typically consist of a blackened flat heat absorbing panel with tubes to allow water to pass through, insulation and glazing material, usually glass, to minimize heat loss. These systems typically consist of heat absorbing plate using materials that are good conductors of heat. The solar radiation is increased by using black material for maximum efficiency. A glazing sheet typically covers the plate to help trap heat and prevent it from escaping back into the atmosphere. Natural convection can pull warm water through the tubes into the storage tank above while cooler water flows downward to the collectors (Tiwari et al., 2016). This process is called thermosyphoning.

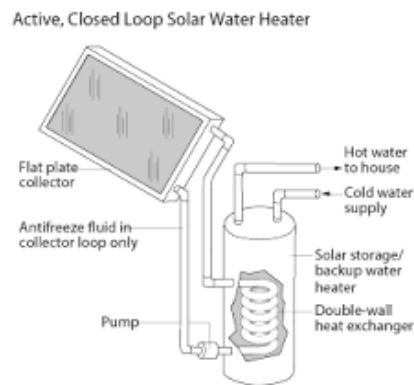


Figure 8: Active, Close Loop Solar Water Heater
Source: (Active and Drainback Closed Loop Solar Hot Water Systems, n.d.)

Evacuated tube collectors (Figure 9) comprise of a row of parallel glass tubes. Each tube consists of a transparent outer tube and a smaller inner tube which is coated in a dark material to absorb solar energy and inhibit heat loss. Air is removed between the two tubes to create an evacuated space, forming a vacuum. This vacuum significantly reduces heat loss caused by convection and radiation.

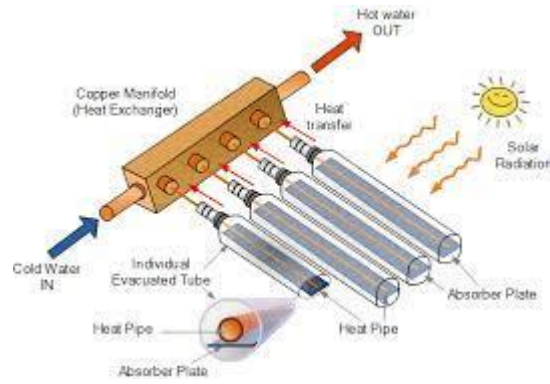


Figure 9: Evacuated Tube Collector
 Source: (Alternative Energy, n.d.)

3.3.3 Passive and Active Heating Systems

There are two main types of solar water heating systems: passive heating which uses natural convection to circulate water, and active heating, which uses a circulating pump to move water through the system. Passive heating systems have fewer moving parts which helps them be more dependable and last longer (Tiwari et al., 2016). Active heating systems uses a pump to increase the efficiency of the water heater while passive systems use natural convection to pull water through the system.

3.3.4 Direct and Indirect Heating Systems

Both passive and active solar water heaters can heat water indirectly or directly. The indirect solar heating system circulates an anti-freeze fluid through the collector and the heat exchange (Tiwari et al., 2016). A direct heating system circulates the water itself through the tubes (Figure 10). In milder climates, such as Kenya where the temperature does not drop below freezing, the direct solar heating system is preferred due to its lower cost.

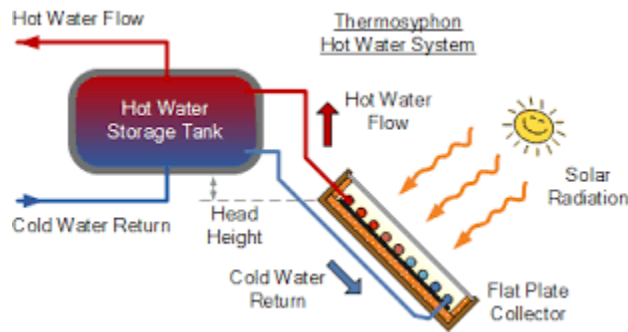


Figure 10: Flatplate Collector with Hot Water Tank
 Source:(Flat Plate Collector for Use in Solar Hot Water Systems, n.d.)

3.3.5 Passive Solar Cooling

Heating and cooling buildings can be regulated using passive solar designs. Windows can be strategically placed to increase cross-ventilation in warm climates. The color of the walls and roof can play a key role in the temperature of the building. Dark surfaces absorb heat better than light-colored surfaces. Changing the color of a roof from dark gray to weathered white can raise the reflectivity of the roof and lower energy use by 20% (Chen, 2004). Elastomeric coatings, single-ply membranes, tiles, and metal roofing can be used to increase the reflectance of the roofs.

3.3.6 Solar Chimneys

Solar chimneys can also be used to passively cool buildings and increase energy efficiency. A dark-colored chimney can be placed on the solar facing side of the building to enhance natural stack ventilation. As the sun heats up the surface of the chimney (Figure 11), the convection of the air pulls cooler air through the building from strategically placed vents on the opposite of the building (*Solar Chimney - Energy Education, n.d.*). The temperature of the building can be

further decreased by running the vent underground, which lowers the air temperature to the ground temperature (Figure 12).

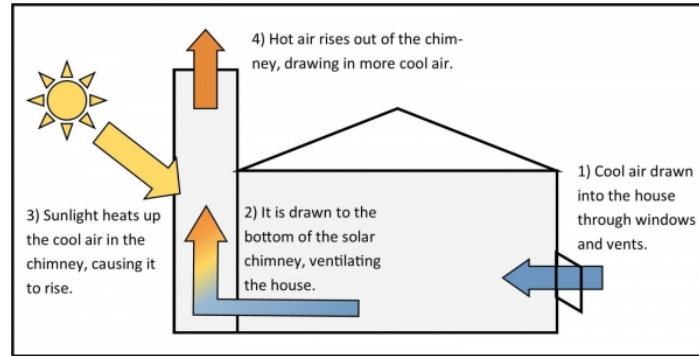


Figure 11: Operation of Solar Chimneys
Source: (The Civile Engineer, n.d.)

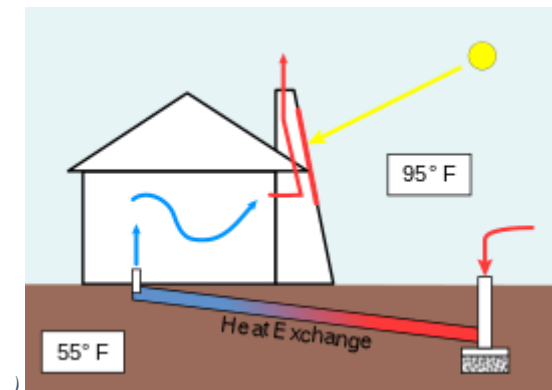


Figure 12: Solar Chimney
Source: (Solar Chimney - Energy Education, n.d.)

3.4 Tourism and Climate Change

The relationship between tourism and climate change is bi-directional. A study conducted by United Nations Environmental Programme (UNEP) and UNWTO estimate that tourism contributes to 5.2% - 12.5% of all global CO₂ emissions with accommodations accounting for 21% of the CO₂ emissions (2012). These emissions can increase the probability of climate change-related weather events. Protections must be in place to reduce the environmental

degradation caused by tourism to protect the industry, the natural areas, reduce the rates of pollution and reduce climate change. A study from Gossling, Scott & Hall found evidence that climate change has adverse impacts on tourism (2012). Destinations which have greater exposure to climate change are less equipped to adapt to the impacts of such effects (Hernandez & Ryan, 2011). This makes it imperative to mitigate climate change effects caused by the industry itself.

3.5 Kenyan Tourism Industry

Currently, Kenya is one of the leading tourist destinations in sub-Saharan Africa. In 2019, tourism made up 8.1% of the country's GDP (Statista, 2020). Additionally, the World Travel & Tourism Council (WTTC) estimates that the total contribution of tourism to GDP will rise to 10.3% by 2025 (WTTC, 2021). As part of Kenya's Vision 2030 Initiative, President Uhuru Kenyatta aims to make the country "a top ten long haul tourist destination offering a high-end, diverse, and distinctive visitor experience" (GoK, n.d.-a). Under the Initiative, Kenya has developed 17 different targets to further strengthen their tourism industry including the development of ecotourism, community-based tourism, and business and conference tourism (GoK, n.d.-a). In Kenya, the tourism industry is currently highly dependent on its natural resources. Safaris and game drives, the Maasai Mara National Reserve, and coastal beaches provide the largest revenue streams in the industry. Climate change will likely impact the industry as the frequency and intensity of extreme weather events, such as heat waves and large storms, is expected to increase.

3.6 Tourism and Renewable Energy

In recent years, ecotourism has seen a surge in popularity. More tourists are interested in minimizing their environmental impact in an industry well known for its environmental damage (Webb, 2020). The increase in global spending on ecotourism is expected to outpace the tourism industry by six times (Jebli et al., 2019). Even so, the UNWTO expects a 25% increase in tourism-related CO₂ emission levels by 2030 from a 2016 baseline (UNWTO, n.d.). High energy consumption is one of the major challenges of sustainable tourism (Pan et al., 2018).

Accordingly, there is a need to rapidly scale up efforts to cut carbon emissions. Kenya's current tourism industry is heavily reliant on biodiversity and the preservation of natural resources. Therefore, there exists increasing pressure to use clean energy sources.

As part of the Tourism Ministry's commitment, the Tourism Cabinet Secretary, Najib Balala, aims to restrict the use of vehicular transportation within all National Parks and Reserves to those that use renewable energy by 2030 (Ministry of Tourism and Wildlife, 2020). The Ministry will also require all hospitality and tourism facilities to adopt renewable energy and circular economy practices within their operations by 2030. These new policies must be taken into consideration when developing new energy practices within the tourism industry. A 2009 study found an absence of causal relationships between output and energy consumption (Sadorsky, 2009). Causal relationships also exist between renewable energy, economic growth, and tourism development (Isik et al., 2018). The causal relationship was not uniform among the countries. This signifies a complex relationship between tourism, economic growth, and renewable energy.

3.7 Tourism and the Socio-Economic Opportunities

Tourism in emerging countries is often regarded as a vehicle to alleviate poverty (Hall & Page, 2009; Meyer, 2007; Rogerson & Pillay, 2013; Rogerson & Rogerson, 2010; Letoluo & Wangombe, 2018). However, foreign development in these sectors can cause the revenue to leave the country, resulting in the local community not receiving social benefits from the industry (Letoluo & Wangombe, 2018). Studies have found that for tourism to result in poverty reduction, community “empowerment” must be achieved. Local communities need to be involved in the development of the industry and hold positions of financial power to keep the revenue within the area.

3.8 Gendered Effects of Electrification in Kenya

A study on the gendered effects of electrification in sub-Saharan Africa, identifies four channels through which electrification can provide women’s empowerment: alleviating time poverty; expanding labor market opportunities; improving maternal health and women’s safety; and changing social norms (Clark, 2021). Time poverty is when an individual must work long hours having little to no discretionary time (Bardasi & Wodon, 2009). Enhancements to women’s economic power can be further expanded by developing sustainable off-grid technologies in a gender-inclusive way. In the absence of renewable energy systems, energy consumption needs were met by diesel generators, connection to existing grids that rely on fossil fuels, burning kerosene, and fuelwood, all which produce CO₂ emissions (Takase et al., 2021b).

Studies show that while women tend to be the primary household energy users, they are rarely involved in decision making on electricity and appliances (Clark, 2021). This is reflected in the

prioritizations of appliances used by both genders or predominantly by men over appliances that are predominantly used by women or lighting in the kitchen. Instead of using electricity, women, who are primarily responsible for the household cooking, often use the light from the cooking fire or kerosene lamps to cook at night. Because of their proximity to the burning fuel sources, negative impacts, from inhaling fumes from the fire or burning lamps, have greater effects on women. The International Labor Organization (ILO) found that, of the deaths related to indoor air pollution from combustible fuels, six out of ten were women (2018).

In traditional gender roles, women are often responsible for energy-intensive household chores including retrieving water, cooking, and cleaning (Dutta et al., 2017). A study from Oxfam further amplifies the gendered effects on women. It notes that in Kenya, women spend on average, 11.1 hours per day on household care while men spend just 2.9 hours (2021). Women spend almost four times more time on household care. Women living in areas with insufficient infrastructure reported spending close to 20% of their time each day collecting water for their household (Oxfam, 2021). By integrating solar water pumping systems into renewable energy development, women stand to benefit through the reduction of time spent on collecting water.

Benefits are further amplified through the reduction in gender-based violence that can occur when women must travel far for water collection (Sarkar, n.d.). Solar powered irrigation can also benefit the women who are in agriculture. Women are also typically responsible for collecting fuelwood for cooking. In Kenya, women spend between 4 - 20 hours per week collecting fuelwood (Jago et al., 2020). While there is still only a small percentage of women (2%) who use electric cooking, COVID-19 has led to increases in the sales of electric pressure cookers (CLASP, n.d.). The increased risk of pre-existing respiratory diseases with complications from

COVID-19 has highlighted the need to reduce exposure to household air pollution in rural communities. Organizations have sought to expand the update of electric pressure cookers by developing financing systems and developing cookers best suited for off-grid electricity (CLASP, n.d.).

Household electrification may contribute to women's economic empowerment. Dinkelman found that five years after electrification, female employment increased by 9.5% compared to the male employment increase of 3.5% (2011). This increase is likely caused by the reduction in time spent on household chores and enabled micro-enterprises. With electric lighting, women have the option to work at night, opening up new options for income generation. While the men are able to work during the day, women, who are the primary caretakers of children, may not be able to work until after their children have gone to bed. Lighting can increase the time available for women to work (Pueyo & Maestre, 2019). It should be noted that one study in Nigeria found that electrification increased the time husbands engaged in income generating activities while wives did not see a change (Salmon & Tanguy, 2016). This led to an increase in household income, however, it did not lower the amount of unpaid work for women. Structural changes must be made to ensure that women have access to labor opportunities and funding for microenterprises. In many cases, land and property are in the man's name and women do not have the collateral to take out loans (Davison, 2019). Without proper measures in place, electrification can exacerbate the differences between men and women.

Access to information can increase exponentially with electrification and can have profound impacts on women's safety and education accompanied by a reduced strain on natural resources. Jensen and Oster found that in India, exposure to cable television reduced the acceptability of

domestic violence toward women, increased enrollment in school for girls but not boys, and decreased fertility which is linked to female autonomy (2009). The effects are quite positive for women's empowerment and are linked to female autonomy. Similar studies have consistently found that increased exposure to television, and radio, which both need electricity, are strongly associated with reproductive behavior (Das et al., 2021; Retherford & Mishra, 1997; Westoff & Koffman, 2011). These effects have been linked with the increased use of contraception by as much as 12% (Retherford & Mishra, 1997). A reduction in the fertility rate can reduce strains on the environment by lowering the amount of natural resource depletion. With a fertility rate of 3.42 children per woman in 2019 (O'Niell, n.d.), reducing the number of children in Kenya will stabilize the population and reduce the strain on natural resources.

Women's safety can be further increased through the electrification of public areas. The installation of public lighting can decrease both physical and sexual violence (World Bank, 2017). In addition to the reduction in crime, a sense of increased security created by the lights also provides women agency. Women may restrict their activities if they do not feel safe walking around at night (Power Africa, 2017). Public lighting can provide safety for women and allow them to feel more safe walking home at night, allowing them to work longer hours. This can affect their educational and business opportunities. Increased safety can benefit people of both genders. However, women are disproportionately affected through reduced mobility.

Electrification of health centers can provide a large benefit to the health of women. In Homa Bay, Kenya, an immediate impact on maternal health was seen with solar power installation. Prior to the arrival of electricity, deliveries of babies could only be performed during the daytime. Women who went into labor at night would have to deliver their babies at home. Now,

with the addition of electric lighting, women in the community can safely perform deliveries at the healthcare center at night (“Creating Sustainable Green Energy Solutions for Maternal and Newborn Health in Kenya,” 2018). Maternal health can also be positively improved through the availability of vaccines and refrigerated medicines. Without electricity, vaccines and refrigerated medicines cannot be stored, greatly reducing access to proper care. In Kenya, 26% of health care facilities still lack electricity (Moner-Girona et al., 2021).

Gender differences in spending, saving, and investing have shown that women’s work may be the most significant contributor to economic development (Dutta, n.d.; Elborgh-Woytek et al., 2013; World Bank, n.d.-d). Women reinvest 90% of their income in their families; focusing on education, healthcare, and children’s welfare as opposed to men who only reinvest 30% to 40% (*Empowering Women in the Developing World: Barriers and Opportunities - Women’s World Banking*, n.d.; Pazarbasioglu, 2017). ENERGIJA has asserted that this increase in women’s economic development is critical to poverty reduction (Dutta, n.d.). Despite these potential effects, there is a lack of opportunities surrounding women’s entrepreneurship. Through gender mainstreaming, we can address the lack of education and financing, and cultural norms that hinder women’s economic empowerment. Projects such as the Women in Energy Enterprise in Kenya (WEEK) have already been developed to implement gender-sensitive approaches to program development. They have successfully been able to build women’s capacity to participate in energy markets (Dutta, n.d.).

CHAPTER 4: ECONOMETRIC MODELING

Econometric modeling can be used to understand the relevant links between tourism and renewable energy in Kenya. Through modeling, we can understand policy implications of renewable energy development. While there are models available that examine the causal relationships of renewable energy in other countries, there are currently no econometric models that focus specifically on Kenya. Studies that examine data available for multiple countries show that the causal relationship between renewable energy and tourism is different depending on the country.

Tourism produces an estimated 5% of global CO₂ emissions of which accommodation accounts for 22% of the sectors emissions (Jiaqi et al., 2022a). Prior to the COVID-19 pandemic in 2020, travel and tourism made up 8.1% of Kenya's total GDP (WTTC, 2021). While tourism is not viewed as particularly polluting, estimates for tourism emissions are expected to quadruple by 2035 (Jiaqi et al., 2022b). The increase in tourism has resulted in an increase in both fossil fuel energy consumption and GHG emissions (Jebli et al., 2019). The UNEP found that in 2011, a third of world travelers were willing to pay between 2-40% more for environmentally-friendly tourism (Pratt et al., 2017).

This study uses the autoregressive distributed lag (ARDL) model to investigate both the short run and long run estimates. Models developed for other countries such as Australia (Khanal et al., 2021) and Pakistan (YaPing et al., 2019) will be used to create the model.

Annual data was retrieved from various sources (Table 2) including the Kenya National Bureau of Statistics (KNBS), the United States Energy Information Administration (EIA), and the World Bank for the years between 1980 and 2018 spanning 39 years.

Table 2: Econometric Variables and Sources

Symbol	Variable	Definition	Source
CO2EP	CO ₂ emissions	Carbon dioxide emissions per capita in metric tons	EIA
ENGP	Energy consumption	Electricity net consumption kilowatt hours	EIA
REP	Renewable energy	Renewable electricity per capita net generation kWh	EIA
lnGDPP	Gross Domestic Product	Natural log of Gross Domestic Product per capita	World Bank
INTOUR	International tourism	Number of tourist arrivals	KNBS

The following empirical model was tested to understand the link between international tourism and energy consumption in Kenya:

$$CO_2EP = \beta_0 + \beta_1 ENGP_t + \beta_2 REP_t + \beta_3 \ln GDPP_t + \beta_4 INTOUR_t + \varepsilon_t$$

where *ln* signifies to natural log, *t* represents time and ε_t represents the error term.

The model entails that the per capita CO₂ emissions as the dependent variable to proxy environmental quality while the natural log of GDP per capita measures aggregate economic activity. Energy consumption per capita and renewable energy per capita, and international tourist arrivals are also included as independent variables. Coefficients β_1 , β_3 , and β_4 are expected to have a positive sign as energy consumption, GDP and international tourism have a

perceived positive association with CO₂ emissions. β_2 is expected to have a negative sign as renewable energy consumption should bring down CO₂ emissions caused by other energy sources. Three tests were conducted within the ARDL procedure: Stationarity, Cointegration, Causality.

4.1 Stationarity

A unit root test for stationarity must first be conducted for time-series data. In this study, the augmented Dickey-Fuller test was used to test for stationarity and ensure errors are not correlated. The following augmented test equation was used to test if the first difference of a variable is stationary (Principles of Econometrics, 5e). This would result in an integrated order of I(0):

$$\Delta y_t = \beta_0 + \gamma y_{t-1} + \sum_{s=1}^{p-1} \beta_1 \Delta y_{t-s} + \varepsilon_t$$

where ts is the relevant time-series variable, Δ is the first difference operator, γ is the parameter of interest, $p - 1$ is the maximum lag order and v_t is the error term.

The augmented Dickey Fuller test was further used to evaluate whether an intercept or trend were appropriate:

$$\Delta y_t = \beta_0 + \gamma y_{t-1} + \lambda t + \sum_{s=1}^{p-1} \beta_1 \Delta y_{t-s} + \varepsilon_t$$

where λt represents the deterministic trend.

In this model, the augmented Dickey-Fuller test (Table 3) showed evidence that all variables were nonstationary at the level I(0) but were stationary at the first difference I(1). Hence, it is appropriate to continue to a bound test.

Table 3: ADF Unit Root Test

Variable	At Level	First difference
CO2EP	-0.389	-7.465*
REP	0.482	-6.347*
LNGDPP	2.013	-4.038*
INTOUR	1.181	-6.688*

*Denotes the test statistic is significant at a 1% critical value.

4.2 Cointegration

Once stationarity is checked, a second test for cointegration must be conducted. Cointegration occurs when the error term $e_t = y_t - \beta_1 - \beta_2 x_t$ is stationary at I(0). This implies the y_t and x_t share similar stochastic trends and never diverge too far from each other. The Pesaran, Shin and Smith bounds test approach was used to examine the long-run cointegration between Kenya's CO₂ emission and the other explanatory variables (Pesaran et al., 2001).

The ARDL framework is as follows:

$$\begin{aligned}
\Delta CO_2EP_t = & \beta_0 + \sum_{s=1}^p \beta_1 \Delta CO_2EP_{t-i} \\
& + \sum_{s=1}^q \beta_2 \Delta ENGP_{t-i} + \sum_{s=1}^q \beta_3 \Delta \ln GDPP_{t-i} + \sum_{s=1}^q \beta_4 \Delta REP_{t-i} \\
& + \sum_{s=1}^q \beta_5 \Delta INTOUR_{t-1} + \lambda_1 \Delta CO_2EP_{t-1} + \lambda_2 \Delta REP_{t-1} + \lambda_3 \Delta \ln GDPP_{t-1} \\
& + \lambda_4 \Delta INTOUR_{t-1} + \varepsilon_t
\end{aligned}$$

Where λ is the depicts the long-run relationship between the variables. β_0 represents the drift constant β_1 to β_4 with the summations correspond to the short-run dynamics of the variables. ε_t depicts the noise in the equation.

The null and alternative hypotheses are as follows:

$H_0: \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$ The series are not cointegrated, the residuals are nonstationary

$H_1: \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq 0$ The series are cointegrated, the residuals are stationary

By utilizing the Pesaran, Shin and Smith bounds test (Table 4) approach we get an F-statistic of 7.545. This F-statistic is greater than the critical value of the I(1) regressor, so we reject the null hypothesis and conclude that the series is cointegrated. Our analysis concludes long-run relationship exists between the CO₂ emissions per capita, electricity consumption per capita, renewable energy per capita, GDP per capita and international tourism between 1980 and 2018.

Table 4: Pesaran, Shin, and Smith Bounds Test

Test Statistic	Value	K
F-statistic	7.545	4
Critical Value Bounds Significance	I(0) Bound	I(I) Bound
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

4.3 Determining Lag Length

To determine the optimum lag length of the ARDL model, the Akaike Information Criterion (AIC) was utilized. Optimal lags for AIC were equal to 4. Max lag lengths of four were used with the ARDL model. Variables that were not significant were dropped to avoid inaccurate analysis.

4.4 Vector Error Correction Model

Due to the presence of cointegration, an error correction model (ECM) was specified to determine the short-run and long run estimates. This model allows for short-run adjustments between the variables while also adjusting to achieve the cointegrating relationship. It also allows for a long run relationship, or a fundamental link between variables. The model adds an error correction term (ECT) to reflect the speed of adjustment of each variable to converge to long-run equilibrium.

$$\begin{aligned} \Delta CO2EP = & -\alpha(CO2EP_{t-1} - \beta_1 - \beta_2 ENGP_{t-1} - \beta_3 LNGDPP_{t-1} - \beta_4 REP_{t-1} \\ & - \beta_5 INTOUR_{t-1}) + \delta_0 \Delta ENGP_t + \delta_1 \Delta LNGDPP_t + \delta_2 \Delta REP_t + \delta_3 \Delta INTOUR_t \\ & + v_t \end{aligned}$$

Table 5: Vector Error Correction ARDL Estimates

Short-Run	Coefficient	Probability
D(ENGP)	-.0010501**	0.022
D(INTOUR)	.0000805**	0.002
D(INTOUR(-1))	.000056	0.030
D(INTOUR(-2))	.0000294	0.119
CointEq	-.1008431	0.122
Long-Run	Coefficient	Probability
ENGP	.0022511**	0.006
LNGDPP	.0366708	0.095
REP	-.000152	0.106
INTOUR	-.0000685**	0.002
ECT(-1)	-.8401168**	0.000

** Denotes statistical significance at 5% level

The coefficient of INTOUR, the measure of international tourism implies a 1% increase in international tourism will lead to a 0.007% decrease in CO₂ emissions per capita. This signifies that international tourism has a negative impact on per capita CO₂ emissions.

4.5 Descriptive Statistics

Table 6 shows the descriptive statistics and correlations of variables. The Jarque-Bera statistics show that only ENGP, REP, INTOUR are normally distributed. The natural log of GDP is taken

to stabilize the variable. CO2EP, ENGP, LNGDPP and INTOUR are positively skewed while REP is negatively skewed. The Breusch-Pagan Test for heteroskedasticity, the Durbin-Watson test and Breusch-Godfrey test for autocorrelation were conducted. There is no evidence of heteroskedasticity or autocorrelation.

Table 6: Descriptive Statistics

Variables	CO2EP	ENGP	REP	LNGDPP	INTOUR
Mean	0.295009	133.9725	369.6453	6.366499	1069.528
Median	0.2868114	127.6026	374.9957	6.081484	1000.6
Maximum	0.3733267	184.515	537.8381	7.578971	2027.7
Minimum	0.2428501	105.2047	197.7456	5.425432	365.2
SD	0.0372747	19.41981	69.45612	0.6219976	476.9055
Jarque-Bera	1.964	0.798	0.671	32.563	4.425
Skewness	0.6525886	0.8641434	-.0967978	0.6659788	0.2547302
Kurtosis	2.470184	3.055404	3.302449	1.977221	1.898465

4.6 Interpretation of results and policy implications

The present econometric model aims to identify the causal links between tourism and CO₂ emissions within the Kenyan context. Of particular interest is the long-run relations between the variables. The long-run vector error correction model provides insight on the relationship between the dependent variable CO2EP and the independent variable. Renewable energy per capita has a negative coefficient signifying an increase in renewable energy would lead to decrease in CO₂ emissions. An increase in GDP and energy consumption will lead to an increase

in CO₂ emissions. This is consistent with what would be expected. The term for international tourism shows a negative relationship with CO₂ emissions. This could be explained through the green tourism hypothesis (Jebli et al., 2019). A substantial portion of Kenya's tourism is based on biodiversity and nature conservation. Dependency on maintaining these locations could drive countries to reduce their pollution emissions.

The empirical findings suggest several policy implications. First, encouraging advancements in clean technologies through renewable energy seems to enhance environmental quality. The government should support the development of the tourism sector which will help support the reduction of CO₂ emissions.

Limitations to this study include the small sample period. The study only covers the period from 1980 to 2019 due to data unavailability for the preceding years. Further improvements of this study would be to include the addition of domestic tourism. As Kenya aims to expand tourism beyond nature-based tourism, it will be interesting to see the changes in the impact of tourism on CO₂ emissions.

CHAPTER 5: CASE STUDIES

5.1 Introduction to Regional Case Studies

Three tourism companies located in Machakos County, Kenya were studied within this project: Vota Ranch, Lukenya Motorcross, and Lukenya Resort. These three tourism companies are nature-based tourism companies with goals to reconnecting Kenyans and other tourists to nature. They are engaged in community development projects and environmental conservation. Each have encouraged plant growth on their property through tree planting and irrigation. They were in the process of transitioning all or part of their operations to captive solar power. *Captive power* refers to electricity that is generated and maintained by a commercial energy user for their own consumption (Amin et al., 2021).

5.2 Case Study 1: Vota Ranch

Vota Ranch is an events venue and eco-farm which offers team building, events space camping, and outdoor space. There is an on-site restaurant, and a variety of lodging options range from camping to cottages. Their guests come mostly from the local area in Machakos County and from Nairobi. Currently, in their early stage of beginning the business, seventy-five percent of the guests are domestic while 25% are international. Vota Ranch is a family-oriented venue hosting family fun days on Sundays where families visit to enjoy a barbeque lunch and spend the day at the Ranch. Vota Ranch offers a venue for weddings, team building photo/video shoots, retreats, camping, and outdoor fitness activities. During holidays and weekends, the site hosts special events for couples and families to enjoy fresh air, good food, and enjoy each other's company.

5.2.1 Clientele

Target clientele for Vota Ranch are local families within the Machakos County area. As stated earlier, domestic guests currently make up 75% of their customer base with the rest visiting internationally. To attract families, Vota Ranch offers weekly barbeques on Sunday where families can enjoy lunch and outdoor activities such as tug-of-war, a bouncy castle are in-line to bring in families such as the Sunday BBQ.

5.2.2 Activities

Vota Ranch serves a diverse range of clientele. While most guests who visit come from the local area in Machakos county, many come from Nairobi, Kenya's capital city, to get away from the hustle and bustle of urbanization. A quarter of their clientele are international travelers. The staff at Vota Ranch are very proud to offer an event venue that is ideal for weddings, team building activities and photo shoots. The on-site restaurant generates the most revenue for the business.

As a business that markets itself as an eco-farm, Vota Ranch attracts customers who are concerned about the environment. Customers have voiced their concerns about the use of plastics, their food sourcing strategies and have offered to share ideas to make Vota Ranch a more environmentally sustainable business. An increase in the concern for the environment, within their clientele demonstrates a need to examine their business activities and improve sustainability measures.

5.2.3 Eco-Farm

Beyond the events venue, Vota Ranch runs an on-site farm. Crops produced on the farm include tomatoes, lettuce, cowpeas (*kunde*), country (*kienyeji*) chicken, amaranth (*terere*), spinach, pepper (*hoho*), corn, banana. Mango trees are also planted. Harvested crops are used to prepare meals at the on-site restaurant and are available for purchase. To give back to the community, Vota Ranch conducts tree planting events.

5.2.4 Accommodations

An assortment of accommodations is available at Vota Ranch from tents to a family house with two ensuite rooms, a sitting area, and large balcony. These rooms are set at different price points to cater to the needs of different clientele. On average, guests stay for 2-3 nights.

5.3 Case Study 2: Lukenya Motorcross

Lukenya Motorcross was established in 2006 to provide recreational sport, allowing people to view the many wildlife in the area. What had started as a hobby, blossomed into a business over the years. During the nascent years of Lukenya Motorcross, the surrounding area was home to plenty of large game wildlife including giraffes, zebras, elands, wildebeests, and antelopes. The company was mainly founded with the mission to providing quad biking services and recreational sport to the local community. However, due to the encroaching development from Nairobi, wildlife in the area has since migrated away, towards the nearby hills. It was noted that during the past seven years, the area has not seen any large animals. The reduction of wildlife has negatively impacted the Lukenya Motorcross because they are no longer able to consistently

provide services such as a self-drive safari. Over the years, they have expanded to offer other amenities including a bar, restaurant, guest rooms, and a pool. While they still offer quad biking, they must offer it without the expectation of seeing wildlife. Quad biking for wildlife has shifted to the development of a quadbike obstacle course and team building activities.

5.3.1 Long term goals for Lukenya Motorcross

Lukenya Motorcross would like to continue as a boutique hotel in the future rather than expand into a larger business. This model has proved successful for their business, and they are able to provide an engaging experience for their guests. However, they continue to have plans to improve their business. One new area they would like to explore is to offer wildlife ATV safaris in the nearby hills. Since Lukenya Motorcross' original business goal was to provide ATV services to view the natural wildlife, reincorporating their original goal would allow them to stay true to their *raison d'être*. To successfully offer these services, Lukenya Motorcross plans to switch their gasoline-powered ATV fleet to new battery-powered ATVs. The combustion engine of a gasoline-powered ATV ranges from 85 decibels to 100 decibels which is categorized as “hazardous” noise levels by the Institution of Occupational Safety and Health (IOSH) (*Occupational Health Toolkit*, n.d.). A battery-powered ATV which does not have a combustion engine is nearly silent when running. The reduction of noise pollution allows guests to get closer to the wildlife without disturbing them and the elimination of tailpipe emissions alleviates strains on the local ecosystem. To accommodate battery-powered ATVs, Lukenya Motorcross will need a reliable source of energy. Based on the unreliability of the national grid in the area, Lukenya Motorcross will need substantial investment renewable energy to ensure ATVs are able to run without service interruptions.

5.4 Case Study 3: Lukenya Resort

Lukenya Resort started off as a hobby project, similar to Lukenya Motorcross. It is run by a family as one of several business activities. The family saw a need for a hotel to accommodate the local university, and other local unmet markets. The target clientele are neighbors, corporates, schools, local universities, as well as the local manufacturing companies. They offer services including swimming, accommodations, team building activities, hiking, and other events. Lukenya Resort developed the local land which was largely undeveloped prior to their arrival. Lukenya Resort is currently 100% solar powered. The activities at the resort that use the highest energy are the swimming pool, the borehole, kitchen, entertainment system, and lighting. They currently offer eight guest bedrooms and hope to expand. Lukenya Resort also hopes to engage in community development through the extension of the national grid to the area. They will fund the extension which will allow neighbors easier access to electricity.

5.5 Machakos County

All three tourism companies are situated in Machakos County, Kenya, just 43 miles southeast of Nairobi. Machakos County has a population of 1,421,932 with a population density of 235 people per sq. km (“2019 Kenya Population and Housing Census Volume I,” n.d.). The climate is semi-arid, relying on a bimodal rainfall pattern (Machakos County Government, 2021). The rainy season lasts for 8 months from October to May with peaks in November and April (Weatherspark, n.d.). The county’s proximity to the equator means abundant sunlight is available throughout the year.

Due to the proximity of Machakos County to Nairobi, connection to the national grid system is available. The national grid is managed, operated, maintained, and distributed solely by Kenya Power and Lighting Company (KPLC). However, a major challenge facing the national grid is the lack of reliability. Machakos County residents estimate that they are unable to use their national grid connection due to power outages a third of the time, occurring on average, once every three days. According to the World Bank, nationwide, 48.8% of the population experience power outages anywhere between three to 14 hours a week (Bhatia & Niki, 2016).

Two renewable energy sources have been identified in Machakos County: wind and solar. Certain regions in the area have favorable wind speeds of 8 to 14 meters per second for a generation capacity above 150 MW. Machakos County is located at the latitude of 1.5° S. Solar radiation of an average 5.18 kWh/m² per day. The Global Horizontal Radiance in Machakos County ranges from 2000- 2200 kWh/m² per year (Machakos County Government, 2021). Under the Energy Regulations Act of 2012, all facilities utilizing over one hundred liters of hot water per day must use a solar water heating system. Solar home systems and solar-wind hybrid projects are also viable.

Wind speed in Machakos County is between 6.4 – 7.7 mph. EIA recommends wind turbines to be placed in areas where wind speeds reach at least 9 mph for small wind turbines. Consistent electricity is key for the tourism industry to provide guests with the proper amenities.

Solar panels should be facing the direction of the sun to allow for optimal energy generation. Table 7 depicts the optimum angle of solar panels for Machakos County. Based on the location of Machakos County, the optimum tilt of fixed solar panels that cannot be adjusted is 89 degrees

from vertical (Boxwell, n.d.). If adjustable solar panels are installed, they should be adjusted to the following angles based on the time of year.

Table 7: Optimal Solar Panel Angle for Machakos County

Jan 105°	Feb 97°	Mar 89°	Apr 81°	May 73°	Jun 66°
Jul 73°	Aug 81°	Sep 89°	Oct 97°	Nov 105°	Dec 112°

5.6 Discussion

All three tourism companies are in the process of transition to captive solar power. Both benefits and challenges were identified regarding the adoption of these systems.

5.6.1 Benefits to Transitioning to Captive Solar

Based on conditions within Machakos County, benefits of transitioning to captive solar were identified. While national grid connection is readily available in Machakos County, issues with the national grid utility, Kenya Power and Lighting Company (KPLC) have pivoted investment interest to generating captive power. These issues include increasing power bills, unreliability, and corruption within KPLC (KPLC, 2020; Mutiso & Taneja, n.d.).

5.6.1.1 Increased Reliability

By managing their own electricity, companies can increase the reliability of their systems. One of the biggest complaints customers of the national grid has been the number of power outages

that occur. Kenya reports an average of 19 days of power outages per year, with Machakos County experiencing an average of 5.8 power outages per month (Maende & Alwanga, 2020). These power outages have an adverse effect on businesses and residents. An econometric study by Maende and Alwanga found evidence that power outages led to a 40% drop in profits. Companies that have generate their own power can fix issues more quickly (2020).

5.6.1.2 Decrease in Power Bills

While a transition to captive power requires higher upfront costs, long term cost benefits are seen with the installation of captive power. For example, the cost of electricity for commercial use is Ksh. 18.88 (USD \$0.16)/kWh. An 8-kWh system will cost Ksh. 360,000 (USD \$ 3094.11) per kW or Ksh. 2,880,000 (USD \$24,752.90) total. The total annual AC energy output would be 11,747 kWh a value of Ksh. 221,784 (USD \$1,906.18). If there are no rate increases, it will take about 10 years to recover the cost of the solar PV. Solar panels typically last from 25 to 30 years, making solar PV systems cheaper than the national grid. One interviewee stated that a switch from the national grid to a standalone solar photovoltaic system dropped the utility costs to a third of the original cost. The financial costs of the solar PV system were paid back within two years of installation.

5.6.2 Challenges to Transitioning to Captive Power

While the tourism industry understands the benefits of switching to standalone solar PV systems, there are challenges that they face.

5.6.2.1 Lack of Financing Options

Captive power systems require a substantial amount of upfront capital. Unlike the smaller pay-as-you-go systems available to meet household needs, financing for these large PV systems is difficult to obtain. Financial institutions are hesitant to provide loans for such systems and small businesses must save up to purchase their own solar panels. One business utilizes table banking, an informal group-based funding system where group members make contributions at predetermined intervals from which members can borrow.

5.6.2.2 Lowered Competitiveness with National Electricity

Although the tourism companies stated that the electricity prices have been steadily increasing, there are efforts to reduce the cost. On December 12, 2021, President Uhuru Kenyatta made promises to reduce the cost of electricity by 30% (Ombok, 2021). In January 2022, the electricity cost was reduced by 15%. Another 15% reduction is on the way but has yet to be enacted. This reduction will help KPLC maintain competitiveness, making it more attractive to connect to the national grid.

5.6.2.3 Lack of Access to Net-Metering or Feed-in-Tariffs

Net metering and feed-in-tariffs are both mechanisms to allow utility companies to pay energy producers for energy fed back to the grid. Some other countries have small-scale feed-in-tariffs to promote the investment of renewable energy sources. In Kenya, policy makers have discussed feed-in-tariffs since 2012 but have not yet implemented this design. These mechanisms allow

energy producers to give their excess energy to the national grid. Feed-in-tariffs were developed but implementation was ineffective (Ndiritu & Engola, 2020).

5.6.2.4 Lack of Information Available on Transitioning to Solar Energy Systems

Some companies switched to standalone solar PV systems only after seeing the benefits reaped by a neighbor. Companies rely on word-of-mouth to identify practices that are beneficial to their business. There is a lack of information on installation of solar PV systems, along with maintenance, sizing, and battery storage.

5.6.2.5 Lack of Availability of System Options

One issue in making the transition to renewable energy is the availability of options. Businesses that are not able to commit to a commercial solar PV system can purchase products with built-in solar panels such as solar lighting. While these systems are less expensive than commercial solar PV systems, they are not designed for the hospitality industry. Warm white lighting is preferred within the industry, but these lighting systems are only available in bright white lights. The lack of options available requires hospitality companies that would like to provide an inviting atmosphere to opt for the more expensive solar PV systems.

5.7 Recommendations for Machakos Tourism Companies

A reduction in CO₂ emissions from each tourism company requires understanding the policies, revenue generating activities, and energy generation. Considering the national grid generates 67.8% of its energy through renewable energy sources, a shift to 100% solar will not likely result in a substantial change to the impact on the reduction in CO₂ emissions. Nevertheless, the shift to

100% captive solar energy will reduce the amount of diesel that is consumed when the national grid experiences power outages.

5.7.1 Evacuated Tubes Collectors

Renewable energy development should be tailored to the specific activities present at each business. Lukenya Motorcross currently does not have a passive solar water heater due to low usage of their guest rooms. However, as COVID-19 restrictions lift and more people travel, it is likely that the accommodations will see an increase in their utilization rate. Therefore, Lukenya Motorcross should work to install a passive solar water heating system to comply with water heating policies. A direct passive evacuated tube solar water heating system is likely the most efficient, cost-effective solution to meet Lukenya Motorcross' needs. While these systems tend to be more costly than a flat plate collector, they are less expensive on a per unit of water cost. This system can be scaled based on their projected water usage. One challenge Lukenya Motorcross has faced is that the solar water heating systems work well when they are in use, but do not work well when they lay dormant for a couple of months. Running the solar water heater can address the issues of dormancy. If no hot water is needed, the water can be captured and cooled to be used for watering plants or used for other water consuming activities. This would be a low-cost solution to this issue that would allow Lukenya Motorcross to continue to meet water heating regulations when accommodation utilization rates increase.

5.7.2 Battery Storage

Lukenya Motorcross and Vota Ranch are already connected to the national grid and rely on diesel backup generators when the national grid is down. Utilization of diesel generators results

in CO₂ emissions. One liter of diesel consumed emits an estimated 2.7 kg of CO₂ (Jakhrani et al., 2012). Lukenya Motorcross has a 100kVA diesel generator that kicks in when the national grid loses power. If run on a full load, this device would consume approximately 24 liters per hour and emit 64.8 kg of CO₂ per hour. To get mitigate risk from power outages and decrease reliance on diesel generators, they should increase investments in batteries storage. These batteries can be connected to their existing systems to provide power through blackouts. In terms of CO₂ reduction, investing in battery technology will provide the most benefit as it helps move away from the usage of diesel generators. Batteries that are powered by the national grid will still have most of their energy come from renewable energy sources.

5.7.2 Enhance Renewable Energy Knowledge Through Associations

While there are some hotels that have successfully converted their entire system to use captive solar energy generation, it is evident that there is a lack of readily available information on converting to a purely renewable energy generation system. Lukenya Resort mentioned their involvement with the Machakos Hoteliers Association, which comes together to market their businesses through social media platforms and other advertisement avenues. The association could be leveraged to increase the adoption of solar energy use as each hotel. As an association, they can work together to identify best solar energy generation equipment for their businesses. Best practices can be disseminated through the association. The tourism companies frequently work together and share business as they complement each other. By working together to identify the best solar energy solutions, they will benefit through increased knowledge. This can also be used to better understand wind energy generation in the area. While none of the tourism

companies has established a wind turbine, this could be combined with solar energy generation to allow for continued energy generation when there is no sun.

5.7.3 Lower Overall Energy Consumption

A reduction of energy usage can decrease the environmental impact of tourism without changing energy sources. Energy efficiency can be improved through different mechanisms including architectural and behavior changes. Buildings can be designed to reduce the need for active cooling. Changing the color of the roof can result in a 20% decrease in energy consumption. A white roof will result in cooler indoor temperatures than a black roof. This change must be balanced with the aesthetics of the hotel. Other passive cooling design considerations include installing a solar chimney. Lastly, energy usage can be reduced through changing social behavior of guests. A study on the impact of social norms on environmental conservation in hotels suggests that encouraging guests to reduce energy consumption through the use of descriptive norms will help reduce energy usage more than encouraging the guests to reduce energy consumption for environmental purposes (Goldstein et al., 2008). While this study focused on towel reuse, this could also be applied to turning off the lights or reducing water usage.

5.7.3 Electrifying All-Terrain Vehicles

One long term recommendation is for Lukenya Motorcross to switch from diesel powered ATVs to electric ATVs. Lukenya Motorcross hopes to expand their motocross activities by identifying a new location for a game drive. As wildlife migrate away from the encroaching urbanization, the business may need to host game drives within national parks. In anticipation of the Tourism Ministry's policies to restrict vehicle access to only electric vehicles in 2030, Lukenya

Motorcross should start shifting their fleet of ATVs to electric. Although this is one of their most CO₂ emitting activities, making the shift to electric ATVs requires considerable amount of capital and requires reliable electricity. It is therefore necessary to ensure that the company has substantial backup generation of clean energy through solar panels and batteries prior to *switching their entire fleet* of ATVs to electric.

5.7.4 Agrivoltaics

One final solution is to develop an agrivoltaic system. Vota Ranch has a small farm that is used to provide food for their restaurant. One solution for increasing solar production would be to mount the solar panels above their farm. This will allow them to increase them to place the solar panels away from the guests, potentially increase their crop yield and harvest rainwater from the solar panels. One thing to note is that studies on agrivoltaics are still limited and the installation of an agrivoltaic system would need to be carefully planned based on the crops and the surrounding areas.

5.8 Recommendations for Policymakers

Two strategies must be employed simultaneously to achieve universal energy access by 2022 in Kenya: grid expansion through extension and densification; and the development of off-grid solutions. The first strategy aims to build on the existing national grid. Expansion of the grid system can reach new areas and communities or reach households living close to the local utility grid who are not yet connected. The second strategy operates independently from the national grid. Because off-grid solutions are unbound from any existing infrastructure, they can reach rural communities that are further from the national grid faster.

5.8.1 Increase support for small-scale renewable energy

The Kenyan government has made great strides to renewable energy generation. They have developed feed-in-tariffs that benefit utility-scale energy generation. However, there is a lack of support of small-scale business owners to use 100% renewables. Financing options should be provided to help small businesses reduce their CO₂ emission. Loans made available for small businesses to implement climate-smart solutions would help decrease overall CO₂ emissions and help the country reach their Nationally Determined Contribution goals of reducing 32% of GHGs by 2030 (Nationally Determined Contributions (NDCs) | UNFCCC, n.d.).

At the same time, this would help small businesses free up capital to pursue other business endeavors. Clean energy incentives will help move away from diesel generators. Similarly, incentives should be developed for designing buildings with net-zero carbon emissions in mind and opportunities for retrofits. Foreign investors, within the tourism industry, have more capital to switch the clean energy. While new policies, in the tourism industry, that work toward a sustainable industry are good for the climate, it can be prohibitive to emerging businesses. These policies can favor foreign businesses which have the capital to make these changes while boxing out local companies. It is therefore necessary to aid local tourism businesses that are aiming to meet the new sustainable tourism requirements.

5.8.2 Infrastructure Development

Frequent power outages of the national grid system make it difficult for Kenyan businesses to rely on the national grid for their energy needs. This is resulting in a mass exodus of Kenyan power users from the national grid. While increasing access to electricity is essential, ensuring

the sustainability of the electrical grid is equally key. Without sustainable infrastructure, those who benefit from the increased access to electricity will be faced with challenges in the future. Accordingly, the maintenance of the existing national grid should be prioritized. Increased reliability will attract more users to connect to the grid to meet their energy needs. This will also help generate revenue for KPLC to develop better infrastructure for grid extension. Failure to strengthen the existing system will result in additional customers developing their own systems and a loss of revenue for KPLC.

Kenya can achieve simultaneous growth in tourism and renewable energy by developing strong policies to guide the development of renewable energy. Tax incentives can be utilized to encourage investment in renewable energy development. Infrastructure within the KPLC, which already produces most of its electricity from renewable energy should be strengthened and aging infrastructure should be replaced to allow businesses to rely on the national grid for clean energy. Without reliable energy from KPLC, organizations must install their own renewable energy systems to stay competitive. This can reduce the overall profits of the tourism industry.

5.8.3 E-Waste Regulations

The lifecycle of solar panels and batteries need to be taken into consideration to explain the full impact of renewable energy. Currently, Kenya's plan to increase renewable energy fails to address the environmental impacts of renewable energy products at the end of the life. E-waste management programs must be implemented to ensure that the hazardous waste found in solar panels and batteries do not exacerbate the climate crisis.

CHAPTER 6: OPPORTUNITIES FOR FURTHER STUDY

There are several areas for further study. Within the ARDL model further modeling could include studying the relationship between domestic tourism and CO₂ emissions. Domestic tourists may have different motivations in tourism and may cause different impacts on environmental quality. Studying the causal relationships of domestic tourists will further provide a more robust analysis of the tourism industry. In addition, renewable energy per capita could be further broken down to analyze the specific impact of solar energy on CO₂ emissions. As solar energy is often developed on a different scale as the other sources of renewable energy, it may have a different impact on CO₂ emissions not captured by the general model.

This research was conducted during the COVID-19 pandemic, severely limiting travel and interaction with the three tourism companies within the case study. Information available on the internet was limited and in-person discussions would have been better able to fill in the gaps in information. Value would be added to this research by visiting the location of each business and understanding the interaction between the companies and its community. This would allow for in-depth discussions with follow up questions to better paint a picture of their situation.

Other opportunities for study would be to survey tourists at each company to better understand the make up the clientele. While each company provided descriptions of their clientele, without the firsthand information from their clients, it is difficult to make assumptions about the clients. In addition, discussions with community members could further help provide context of the companies as a pillar of society. Interviews with Kenyan government officials on the future of renewable energy regulations would provide valuable insight as well.

CHAPTER 7: CONCLUSION

This paper aims to identify the future trajectory of renewable energy generation within the tourism industry in Kenya. The ARDL modeling found that there was a negative relationship between CO₂ emissions and international tourism in Kenya. This signifies that tourism in Kenya is focused on environmental preservation and should be further supported through government policy. Renewable energy efforts also show a negative relationship with CO₂ emissions signifying that an increase in renewable energy does not increase CO₂ emissions. and Efforts to increase energy should focus on the development of renewable energy projects. Since the national grid already generates much of its energy through renewable energy, policies should be aimed at further increasing the proportion of generation through renewable energy. Existing infrastructure of the national grid should also be strengthened to reduce the need for tourism companies to rely on the development of their own solar PV systems. Strengthening the existing infrastructure could also lead to a reduction of power outages and a reduced reliance on diesel generators. Policies should also be strengthened to allow residents and companies to generate their own renewable energy through improving the availability of financing for these projects.

This project finds evidence that renewable energy technologies are economically attractive to tourism companies. The costs of water pumping, heating, and lighting are considerably lower when using solar energy systems than using electricity or a diesel generator for the same service. However, barriers to transitioning to solar PV systems exist. There is a lack of financing available for small commercial businesses to fully switch to private renewable energy. Funding mechanisms exist for large scale commercial energy such as feed-in-tariffs and small-scale funding such as PAYG allows households to meet their basic needs. However, robust funding

mechanisms do not yet exist for medium-scale solar. Expansion of funding mechanisms to provide renewable energy to these companies would allow for reallocation of funding to building other business opportunities. An increase in solar energy development should also focus on product end-of-life. Development of e-waste regulations are needed to maintain sustainability of renewable energy projects.

Finally, increasing solar energy development in Kenyan tourism companies is a viable solution. Companies should assess the distinct aspects of their businesses to determine where passive or active solar energy generation would be the most beneficial. Key drivers of solar energy development include existing and future policy such as the push for vehicle electrification within national parks.

APPENDICES

A.1 Matrix of Three Case Studies

	Vota Ranch	Lukenya Motorcross	Lukenya Resort
Background	Vota Ranch was established in 2014. Prior to the arrival of Vota Ranch, the land had few trees and no grass. The area has since been converted into a lush oasis. Vota Ranch now offers family friendly activities, an eco-farm and event space. Vota Ranch also hosts an athletics program which trains and sponsors promising runners in Kenya.	Lukenya Motorcross started in 2006 as a hobby project for quad biking when there was still plenty of wildlife in the area. The location had two trees. The owner of Lukenya Motorcross rehabilitated the land by planting grass and trees. Since then, increased urbanization has driven the wildlife out of the area into the neighboring hills. The hobby eventually evolved into a business and Lukenya Motorcross explored additional income generating activities such as accommodations and a restaurant.	Lukenya Resort started out as a hobby and is run by a family as one of several business activities. The family built the resort on land that they owned as they saw the need for a hotel to accommodate the local university and other markets. The land where the resort was located was largely undeveloped with very few trees.
Target Customer	Vota Ranch targets guests with families, locals in the Machakos area, people from neighboring cities as well as international guests.	Lukenya Motorcross aims to reach guests in local areas and from Nairobi. Currently, eighty percent of their guests come from Nairobi, while twenty percent come from the local areas.	Lukenya Resort aims to reach neighbors, corporates, schools, local university, and manufacturing companies.
Typically Weekend Guest Size	10-40 people	15-70 people	50-100 people

	Vota Ranch	Lukenya Motorcross	Lukenya Resort
Activities Offered	<ul style="list-style-type: none"> • Team building activities • Weddings • Events • Eco-farm • Athletics • Accommodation • Barbeques • Restaurant • Horseback riding (on weekends) 	<ul style="list-style-type: none"> • Motorcross • Barbeques • Accommodations • Team building activities • Swimming • Restaurant 	<ul style="list-style-type: none"> • Swimming • Accommodations • Team building activities • Hiking • Events
Available Accommodations	Tents, cottages, family house with ensuite	Fourteen guest rooms including tents for camping	8 guest rooms
Accommodation Rates	Ksh. ~4,500 (USD \$39) – 15,000 (USD \$ 129)	Ksh. ~3,500 (USD \$30) -7,000 (USD \$60)	Ksh. ~5,500 (USD \$47)
Main Revenue Generation	Restaurant and events	Quad biking and restaurant	Swimming and accommodation
Activities with the Highest Energy Usage	Bouncy castle, lights, storage, and water pumping	Heating for rooms, kitchen, water pumping (borehole), swimming pool	Swimming pool, water pumping (borehole), kitchen, entertainment system, and lighting
Current Energy	<ul style="list-style-type: none"> • National grid connection • Hybrid inverter system with 5,400 W capacity and 16 240-volt batteries • Evacuated tube solar water heating system with capacity to heat 300L of water to 60°C • Petrol diesel generator for back up 	<ul style="list-style-type: none"> • National grid connection • Solar lights • Solar borehole • 100 kVA diesel generator with 200L reserve capacity for back up • Petrol-powered quadbikes 	100% Captive power solar energy generation

A.2 Cost of Electric All-Terrain Vehicles

The average cost of a new ATV was USD \$7,000 (Ksh. 814,450.00) in 2019. Electric ATV USD \$9,000 (Ksh. 1,047,150.00). Current electric ATVs have a battery range of 20 – 50 miles on a full charge (*Electric ATVs/UTVs | Silent, Eco-Friendly | DRR USA*, n.d.). Each charge takes about 4 – 10 hours depending on the battery and the charger. Gas powered ATVs have an average efficiency between 15 and 20 miles per gallon (MPG). Table 8 shows the cost of various fuels in Kenya. Using this information, we can calculate the cost of fuel for an ATV. The cost of gasoline to ride the ATV for fifty miles is Ksh. 1235.23 (\$USD 10.62) to Ksh. 1646.98 (\$USD 14.16) (Nikki, 2021). The same fifty miles for an ATV with a 12kW battery pack (such as the Polaris Ranger EV) will cost Ksh. 265.80 (\$USD 2.28), only 20% of the cost of gasoline (*Polaris RANGER: UTVs - Utility Task Vehicles*, n.d.). The electric ATV will have less maintenance cost because it has fewer moving parts.

Gasoline cost for 50 miles on a traditional ATV

$$\text{Total cost of gasoline} = \# \text{ of miles} \frac{(\text{Cost of Gasoline per Gallon})}{\text{MPG}}$$

$$\text{Ksh. } 1646.98 = 50 * \frac{(\text{Ksh. } 130.54/\text{L} * 3.785\text{L/gallon})}{15\text{MPG}}$$

$$\text{Ksh. } 1235.23 = 50 * \frac{(\text{Ksh. } 130.54/\text{L} * 3.785\text{L/gallon})}{20\text{MPG}}$$

*3.785 liters equals 1 gallon

Cost of electricity for 50 miles on an electric ATV

*Total cost of electricity = battery capacity * cost per kWh*

$$Ksh. 265.80 = 12 \text{ kw} * Ksh. 22.15 \text{ per kWh}$$

Table 8: Cost of Fossil Fuels

Fuel	Price
Gasoline	Ksh. 130.54 (USD \$1.12) per liter
Kerosene	Ksh. 106.46 (USD \$0.91) per liter
Charcoal	Ksh. 60.74 (USD \$0.52) per kilogram

A.3 Kenya Statistics

This section includes on general statistics on the trajectory of Kenya’s population, energy generation and GDP to show the trends in recent years. The population of Kenya has increased steadily while GDP has seen an upward trajectory since 2005 indicating that overall, the standard of living for Kenya has gone up in recent years. In the last ten years, Kenya has seen a dramatic growth in renewable energy generation. Of this, geothermal energy has progressed the most rapidly. Although solar energy is only a small portion of the energy generation mix, its scalability makes it easier for residents to privately install.

The figure 16 and 17 provide context on the climate in Machakos County, Kenya. They depict the bimodal rainfall patterns along with the temperature changes throughout the year.

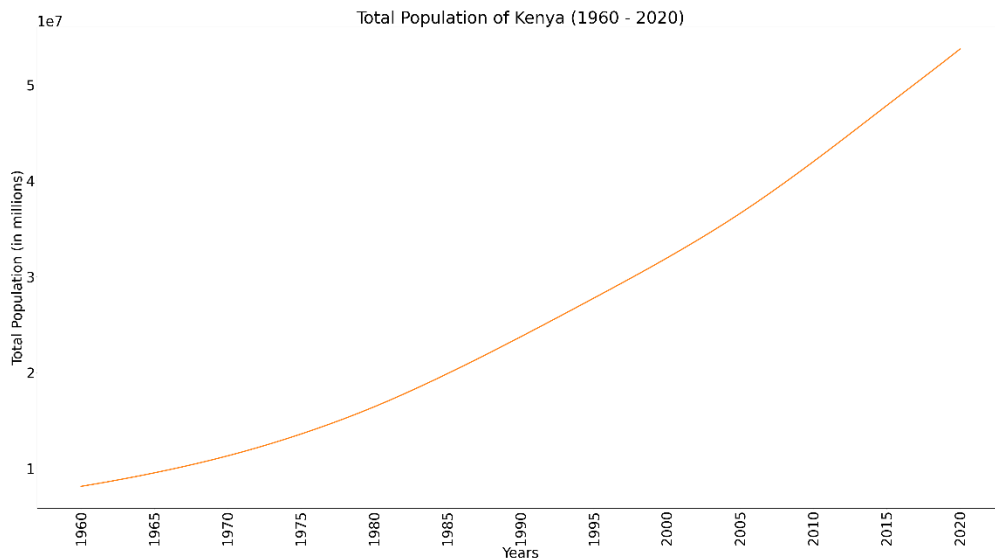


Figure 13: Population of Kenya from 1960 - 2020
Source: World Bank, n.d.

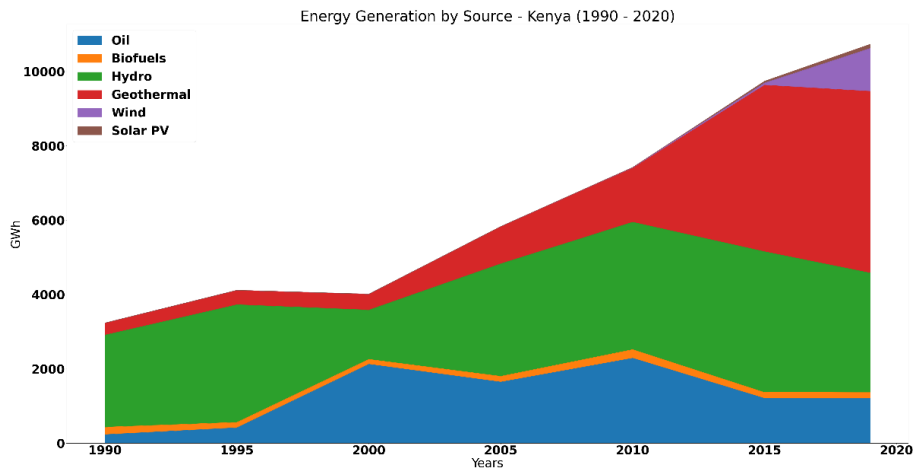


Figure 14: Energy Generation by Source
Source: World Bank, n.d.

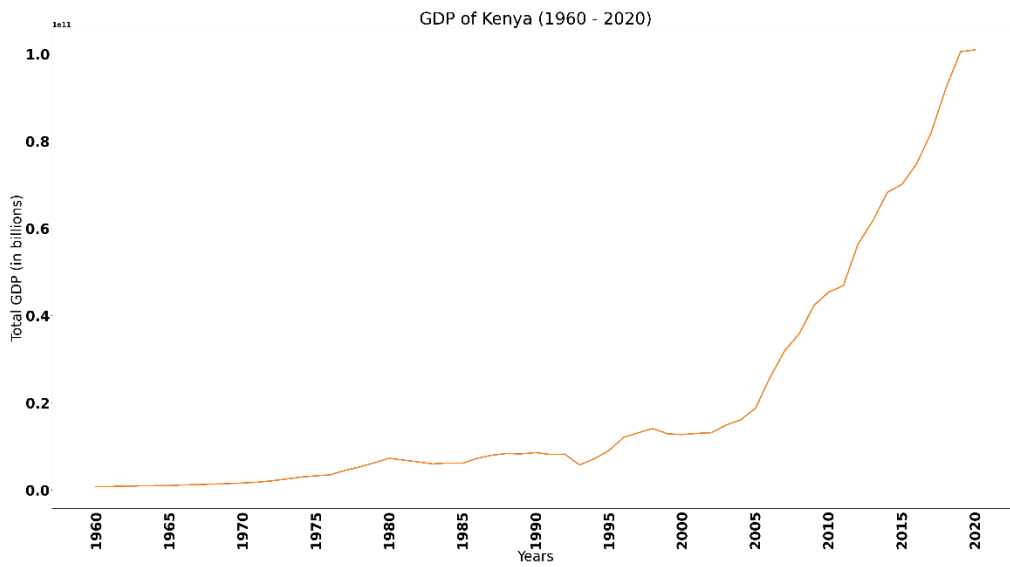


Figure 15: Kenya GDP
Source: World Bank, n.d.

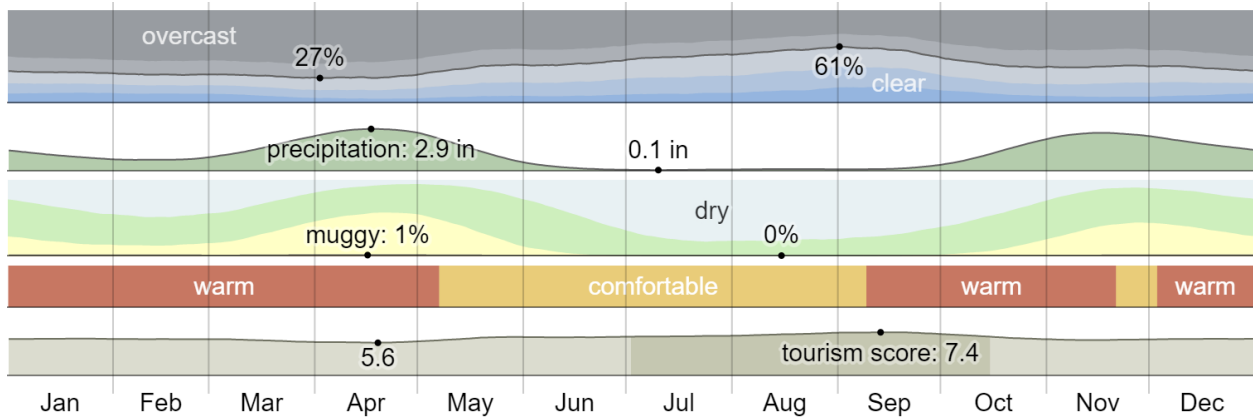


Figure 16: Climate Averages in Machakos County, Kenya
Source: Weatherspark, n.d.

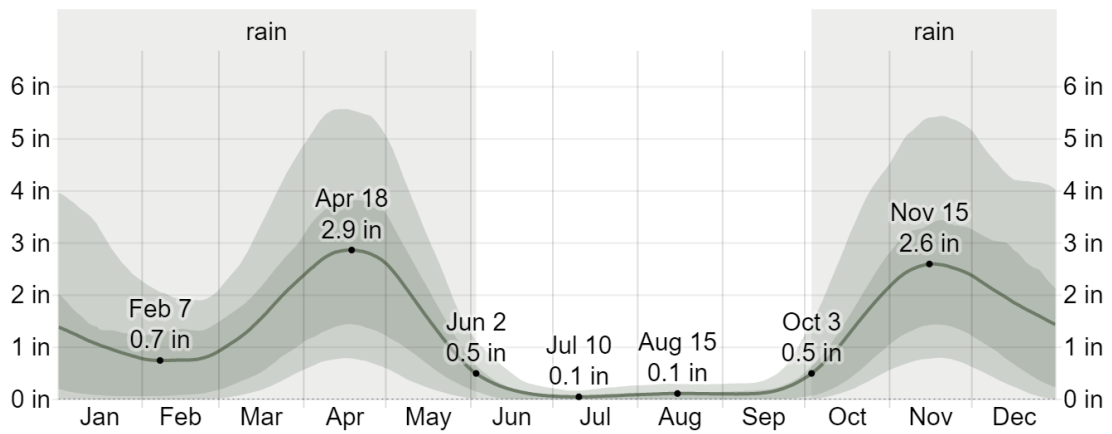


Figure 17: Average Temperatures in Machakos County, Kenya
Source: Weatherspark, n.d.

A.4: Changes to Landscape at Vota Ranch

The land in Machakos County is typical of a semi-arid region. There is very little vegetation. To attract guests, each tourism company planted trees and irrigated the lands to create lush gardens. Today, the landscape is unrecognizable from what it once was.



*Figure 18: Vota Ranch Prior to Establishment
Source: Photo provided by Vota Ranch*



*Figure 19: Vota Ranch Campfire Site Today
Source: Photo provided by Vota Ranch*

A.5: Solar Energy at Case Study Sites

Different types of solar energy systems were observed at the various case study sites. Both passive solar systems and active solar systems were present. Lukenya Motorcross mainly utilized standalone solar lighting systems while Vota Ranch's systems was more robust including batteries, a hybrid inverter, solar panels, and an evacuated tube solar water heater.



*Figure 20: Solar Lighting at Lukenya Motorcross
Source: Photo provided by Vota Ranch*



*Figure 21: Battery Storage at Vota Ranch
Source: Photo provided by Vota Ranch*



*Figure 22: Hybrid Inverter at Vota Ranch
Source: Photo provided by Vota Ranch*



*Figure 23: Evacuate Tube Solar Heater at Vota Ranch
Source: Photo provided by Vota Ranch*

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