UNIVERSITY OF NAIROBI

INTEGRATING GIS FOR CLIMATE-RESILIENT ASSESSMENT OF OPTIMAL LOCATIONS FOR PV SOLAR POWER PLANTS IN KAJIADO COUNTY, KENYA

BY

VERAH OKEYO

I54/40961/2021

A Dissertation submitted for the award of Masters of Science in Climate Change, in the Department of Meteorology of the University of Nairobi

NOVEMBER 2023

PLAGIARISM STATEMENT

The dissertation has been written by me in my own words. Where quotations, pictures, maps or other illustrations from published or unpublished sources or material not resulting from my own experimentation, observation and specimen collection have been used, that have been clearly indicated and acknowledged as such. I am aware that incorporation for material from other or paraphrasing of such material without acknowledgment was treated as plagiarism subject to the custom and the usage of the subject according to the University Regulations on conduct of examinations.

SIGNATURE……………………………………………………..……DATE: 29TH NOVEMBER, 2023

DECLARATION

I declare that this dissertation is my original work and has not been submitted in any other University for a ward any degree. Where other people's work has been used, this has been acknowledged and referenced in accordance with the university of Nairobi's requirements.

SIGNATURE………………………….. DATE: 29TH NOVEMBER, 2023

This dissertation is submitted with our approval as University Supervisors:

SIGNATURE……… ……… DATE…***30/11/2023***………........

PROF. CHRISTOPHER OLUDHE

SIGNATURE…………………….... DATE 30/11/2023……………..……………

DR. JANE WANGUI MUGO

DEDICATION

This research is dedicated to my dear husband Eng. Kenneth Amollo who has made significant contribution in my academic voyage, my late father Elder. Justus Okeyo and my mother Pastor Elizabeth Okeyo for their unfailing support.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude and appreciation to all those who have contributed to the completion of this research.

First and foremost, I would like to thank the Almighty God for His grace has been sufficient in my life.

I am deeply indebted to my supervisors, Prof. Christopher Oludhe and Dr. Jane Mugo for their invaluable guidance, expertise, and unwavering support throughout the entire research process. Their insightful feedback, constructive criticism, and encouragement have been instrumental in shaping this research and enhancing its quality.

I would like to extend my gratitude to the faculty members at the Department of Earth and Climate Sciences at the University of Nairobi for their dedication to excellence in education and for providing me with a conducive academic environment. Their teachings and mentorship have been influential in broadening my knowledge and enhancing my research skills.

I am grateful to my classmates who willingly shared their time, knowledge, and experiences. Their contributions have been crucial in generating the data required to address the research objectives and produce meaningful findings.

I would like to acknowledge the assistance and support received from Advanced Engineering Consultants Limited who sponsored the whole research with necessary resources, and technical assistance. Their cooperation and collaboration have been invaluable in the successful completion of this research.

I would also like to express my appreciation to my family the Okeyos and my dear husband Eng. Kenneth Amollo for their unwavering support, understanding, and encouragement throughout this academic journey. Their love, motivation, and belief in my abilities have been a constant source of inspiration.

Table of Contents

Table of Contents v

List of Tables viii

List of Figures ix

List of Abbreviations and Acronyms x

ABSTRACT xii

CHAPTER ONE: INTRODUCTION 1

1.1. Background Information 1

1.2. Research Questions 4

1.3. Problem Statement 4

1.4. Objectives 5

1.5. Justification for the Study 6

1.6. Scope and Limitation of the Study 8

CHAPTER TWO: LITERATURE REVIEW 10

2.1. Climate-Resilient Factors for Solar Power Plant Viability 10

2.2. Data Collection Constraints for Climate-Adaptive PV Solar Plant 11

2.3. Climate-informed GIS analysis for solar PV system installation 11

2.4. Multi-criteria Decision Analysis (MDC) 12

2.5. Analytic Hierarchy Process (AHP) 14

2.6. Energy Sector in Kenya 17

2.7. The Photovoltaic Systems 18

2.8. PV Systems Siting Criterion 20

2.8.1. Environmental Factors 21

2.8.2. Economic Factors 21

2.8.3. Efficiency/ Technical Factors 21

2.9. Conceptual Framework 22

CHAPTER THREE: MATERIAL, DATA AND METHODOLOGY 24

3.1. Study Area 24

3.2. Data Description 25

3.3. Training of Project Resource for the collection of primary data. 26

3.4. Primary Data Collection Procedure Using Mobile Mapper 27

3.5. Establishing Data Standardization and Integrity 28
3.6. Geospatial Data Processing and Analysis using ArcGIS 28
3.7. Suitability Criteria Development 29
3.8. Assessing Climate-Resilient Factors for Solar Power Plant Viability 32
3.9. Identifying data Collection Constraints for Climate-Adaptive Solar Plants 32
3.10. Suitability Criteria Assignment and reclassification of raster maps 33
3.12.1. Proximity Suitability Analysis 34
3.12.2. Terrain Suitability Analysis 35
3.12.3. Solar Radiation Suitability Analysis 35
3.12.4. Soil Type Suitability Analysis 36
3.12.5. Land Use Land Cover Suitability Analysis 37
3.12.6. Weighted Overlays for Solar PV Suitability Analysis 37
CHAPTER FOUR: RESULTS AND DISCUSSIONS 39
4.1. Introduction 39
4.2. Climate-resilient factors for solar power plant viability 39
4.3. Constraints for climate-adaptive solar plants 41
4.4. Analysis of Suitable Land for PV solar power plant Installation and the reclassification of raster maps 43
4.4.1 Solar Radiation Suitability 43
4.4.2 Soil Type Suitability 45
4.4.3 Slope Suitability 46
4.4.4 Land Cover Land Use Suitability 48
4.4.5 Distance from Roads Suitability 50
4.5. Locations of Schools and Health Centers 52
4.6. Pairwise Comparison matrix 54
4.7. Criteria Weights Assignment 54
4.8. Suitability Map for Solar PV Plant Installation 55
CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS 58
5.1 Conclusion 58
5.2 Recommendations 59
REFERENCES 61

APPENDICES **69**

Appendix 1: Research Questionnaire: Assessing Climate-Resilient Factors for Solar Power Plant Viability 69

Appendix 2: Research Questionnaire: Identifying Data Collection Constraints for Climate-Adaptive PV Solar Plants 71

List of Tables

Table 1: Risks and Mitigation Measures for the study. 9
Table 2: Fundamental Scale... 15
Table 3: Summary of used data, source, duration and their resolution. 26
Table 4:Classification of raster maps into different classes of suitability and their description .. 30
Table 5: Pairwise Comparison Matrix 54
Table 6: Normalized Pairwise Comparison Matrix 55

List of Figures

Figure 1: Grid connected PV system 19
Figure 2: Off grid (Stand Alone) connected PV system 20
Figure 3: Conceptual Framework of the study. Where SPOB 1, SPOB 2 and SPOB 3 stand for specific objective 1, 2 and 3 respectively. 23
Figure 4: Kajiado County Map 24
Figure 5: Mobile Mapper 27
Figure 6: Solar Radiation Suitability map against the reclassified Solar Radiation map for Kajiado County 45
Figure 7: Type of soil Suitability map against the reclassified type of soil map for Kajiado County 46
Figure 8: Suitability Slope map against reclassified slope map for Kajiado county 48
Figure 9: Land Use Land Cover Suitability map against the reclassified land use land cover map for Kajiado County 50
Figure 10: Map depicting the distance from roads in Kajiado County against the reclassified map for distance from roads 52
Figure 11: Schools and Health Centers in Kajiado county 53
Figure 12 :Suitability Map for Solar PV Plant Installation.. 56

List of Abbreviations and Acronyms

Abbreviation/ Acronym	Description
AC	Alternating Current
AHP	Analytic Hierarchy Process
COP21	21st Conference of the Parties
DC	Direct Current
EPRA	Energy Petroleum Regulatory Authority
ERC	Energy Regulatory Commission
FiT	Feed-in Tarif
GDC	Geothermal Development Company
GHI	Global Horizontal Irradiation
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Providers
KenGen	Kenya Electricity Generating Company
KENSOTER	Kenya Soil and Terrain database
KETRCO	Kenya Electric Transition Company
KPLC	Kenya Power and Lighting Company
KRB	Kenya Roads Board
KWH/M^2	Kilowatt Hours per Square Meter
LiDAR	Light Detection and Ranging
LULC	Land Use Land Cover
MCDA	Multi-Criteria Decision Analysis
MoE	Ministry of Energy
MW	Megawatt
N/A	Not Applicable
NEMA	National Environment Management Authority

Abbreviation/ Acronym	Description
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluations
PV	Photovoltaic
QGIS	Quantum Geographic Information System
REA	Rural Electrification Authority
SAW	Simple Additive Weighting
SDG	Sustainable Development Goals
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
UNFCCC	United Nations Framework Convention on Climate Change

ABSTRACT

The aim of this study was to assess suitable locations for photovoltaic solar power plants using GIS in Kajiado County, with a special emphasis on climate resilience. The main objective of this study is to employ GIS for evaluating optimal sites for the installation of photovoltaic solar power plants in Kajiado County. The specific objectives included evaluating climate-resilient factors for solar power plant viability, identifying data collection constraints for climate-adaptive PV solar plants, and conducting climate-informed GIS analysis for solar PV system installation. The primary datasets were: slope, land use land cover, distance from roads and type of soil that were collected using a mobile mapper to validate the secondary data used in this study. The secondary datasets used were: solar irradiance extracted from World Bank, type of soil sourced from Kenya Soil and Terrain database, land use land cover from National Management Authority, Slope data from USGS and distance from roads data from Kenya Roads Board. The methodology involved a systematic approach, beginning with the identification of suitable areas through the analysis of key factors such as solar radiation, slope, distance from roads, land use, and soil type. Subsequently, a crucial step involves the determination of corresponding weights for these factors, ensuring a comprehensive consideration of their relative importance in the decision-making process. Analytic Hierarchy Process (AHP) was applied to determine the corresponding weight of each criterion. The maps were classified into three classes of suitability as, more suitable, moderately suitable and less suitable. The results of this study showed 22% of the area of study to be more suitable, 47% being less suitable and 31% moderately suitable for PV solar plants installation and a map showing the suitability category was created. In conclusion, the utilization of GIS technology for renewable energy assessment has proven to be a potent methodology, offering a robust approach to pinpointing ideal locations for PV solar power plants. This study, aligned with its main objective of using GIS in assessing optimal sites for solar power installations in Kajiado County, underscores the effectiveness of GIS integration for identifying and evaluating suitable areas for solar energy infrastructure. The results of this study can serve as a valuable resource for future planning and decision-making processes in the renewable energy sector, not only in Kajiado County but also in other regions with similar characteristics. Based on the findings, the study recommends the development and implementation of policies supporting the growth of solar energy in Kajiado County, including incentives, streamlined permitting processes, and regulations promoting

sustainable development. Public education initiatives are also suggested to create awareness of renewable energy sources, particularly in remote areas, fostering sustainable practices and reducing dependence on fossil fuels.

CHAPTER ONE: INTRODUCTION

1.1. Background Information

The energy sector in Kenya has experienced transformations in recent times, driven by the government's commitment to expanding access to electricity, promoting renewable energy, and reducing dependency on fossil fuels (Takase *et al*., 2021). Kenya's energy mix primarily consists of geothermal, hydroelectric, and thermal power. Kenya has vast geothermal resources, and it has been actively developing geothermal plants to harness this clean and reliable energy source. Hydroelectric power is another important component, with several large and small hydroelectric plants across the country. Solar energy is of particular importance in Kenya's energy transition due to the country's abundant solar resources (Rambo, 2013).

Kenya lies close to the equator, giving it high solar irradiation levels throughout the year. Solar power offers significant potential to expand electricity access, especially in remote areas where grid connections are challenging. It is also a key solution for diversifying the energy mix and reducing carbon emissions (Ahmad *et al*., 2011). To encourage the advancement of solar power plant development, the Kenyan government has implemented various policies and incentives. One notable initiative is the Feed-in Tariff (FiT) program, which guarantees developers of renewable energy projects, including solar, a fixed tariff for the electricity they generate over a specific period. This program provides investors with long-term price certainty, making solar projects economically viable and attractive (Ndiritu *et al*., 2020). Kenya has also received support from international organizations and development partners for the expansion of solar energy. Projects like the Scaling Solar program, supported by the World Bank, have facilitated the development of large-scale solar power plants in the country (Narbel *et al*., 2021)

Geographic Information Systems (GIS) are powerful tools that enable the collection, storage, analysis, and visualization of geospatial data. When it comes to site selection for photovoltaic solar power plants, GIS technology plays a crucial role in assessing and integrating multiple data layers and parameters to identify optimal locations (Karimi *et al*., 2019).

GIS allows for the incorporation of various spatial datasets, such as solar radiation, land use, topography, proximity to infrastructure, and environmental factors, into a single analysis. Solar radiation data, obtained from satellite imagery or ground-based measurements, provides insights into the availability and intensity of sunlight in different areas. Land use data helps identify suitable areas that are not ecologically sensitive or restricted for development. Topographic data aids in assessing the slope and identifying areas with optimal orientation for solar panels. Environmental factors, including soil type, protected areas, water bodies, and sensitive habitats, help identify areas that require careful consideration during the planning process. By overlaying and analyzing these data layers within a GIS platform, solar power plant developers can identify potential sites that meet specific criteria and constraints (Ruiz *et al*., 2020).

Key data sources for assessing suitable locations for solar power plants in Kenya include solar radiation data, land cover data, elevation data, infrastructure maps (distance from roads), and environmental data such as soil type (Azmi *et al*., 2022). Solar radiation data can be acquired from satellite-based sources like The World Bank data catalogue site. Land cover data can be acquired from the National Environment Management Authority. Elevation data is available through sources like the USGS Earth Explorer site. Infrastructure data can be obtained from Kenya Roads Board. Soil type data, may be accessible through Kenya Soil and Terrain database (Maraun *et al.*, 2010). While these data sources exist, challenges may include data quality, resolution, and availability at the desired spatial and temporal scales. Data gaps and inconsistencies may exist in certain regions or for specific parameters, requiring careful consideration and validation during the site selection process (Maraun *et al*., 2010).

To assess suitable locations for photovoltaic solar power plants using GIS, firstly, the data layers are gathered; solar radiation, land use, topography, proximity to infrastructure, and environmental constraints. Then the administrative data are obtained. Secondly, the data is cleaned and validated to remove errors and inconsistencies, converted to a common coordinate system and resolution handling the missing data appropriately. Thirdly, the various datasets are combined into a single GIS project, overlaid and integrated (Noorollahi *et al*., 2008).

Spatial analysis techniques are utilized to assess the suitability of potential sites considering factors like solar irradiance, slope, land use, distance from roads and soil type then apply specific algorithms or models to evaluate the suitability based on predetermined criteria. Analytical

Hierarchy Process, a multi-criteria decision-making method, is employed to rank and prioritize potential sites. Criteria such as solar radiation, land availability, slope, and soil type are defined. Weights are assigned to each criterion in accordance with their respective significance and each potential site evaluated against the criteria and suitability scores calculated. The results of the suitability analysis and AHP to identify the most suitable locations for solar power plants are then analyzed (Colak *et al*., 2020).

The Olkaria Geothermal and Solar Project in Kenya utilized GIS to identify suitable locations for solar power plants. GIS analysis helped identify areas with high solar potential, taking into account factors like solar irradiance and land availability. The project successfully integrated geothermal and solar energy generation, diversifying the renewable energy mix in Kenya (Kiplagat *et al*., 2011).

While not directly related to solar energy, the Lake Turkana Wind Power Project in Kenya incorporated GIS in site selection. GIS was employed to assess wind resource potential, land suitability, and transmission infrastructure for optimal wind farm siting. GIS analysis played a crucial role in identifying suitable locations for wind turbines, maximizing energy output and reducing environmental impacts. From these mentioned projects it is crucial to ensure accurate and up-to-date data for reliable site selection analysis. Continual data collection and improvement are essential to enhance the accuracy of solar resource assessments and site suitability analysis (Zhang *et al*., 2017). Incorporating multi-criteria decision-making methods like AHP enables a systematic and transparent evaluation of potential sites based on various factors. Assigning appropriate weights to criteria and considering stakeholder preferences contribute to more informed decision-making. Involving relevant stakeholders, such as local communities, government agencies, and energy experts, fosters acceptance and support for solar power plant projects to help address concerns and align project goals with local needs.

Sustainable Development Goal 7, established by the United Nations in 2015, concentrates on guaranteeing availability of affordable, dependable, sustainable, and contemporary energy for everyone. The UNFCCC emphasizes that renewable energy development presents a high-potential mitigation opportunity, capable of achieving emission reductions in line with the 1.5 degrees

Celsius target by 2030. In this context, investments in thermal power, wind, solar energy, enhanced energy productivity, and universal energy access become imperative to meet the objectives of SDG 7 by 2030. Notably, Kenya stands out in Africa for leading the utilization of renewable energy sources, aligning with the vision of achieving sustainable development by 2030 (Rios *et al.*, 2021). Advancements in GIS technology, including higher-resolution satellite imagery and more accurate solar radiation data, will enhance the precision of site selection analysis. Integration of real-time data, such as weather conditions and energy demand patterns, can further optimize solar power plant performance and grid integration (Renne, 2016).

1.2. Research Questions

In order to successfully conduct research on the use of GIS in assessing suitable locations for solar power installation in Kenya, the following questions were addressed:

a) How do climate-resilient factors impact the viability of solar power plants in Kajiado County, Kenya?
b) What are the primary constraints in data collection for implementing climate-adaptive photovoltaic (PV) solar plants in Kajiado County?
c) How can climate-informed GIS analysis contribute to the identification of optimal locations for solar PV system installation in Kajiado County, Kenya?

1.3. Problem Statement

The deployment of photovoltaic solar power plants in Kenya faces the challenge of identifying suitable locations that maximize energy generation while considering various spatial, environmental, and socio-economic factors. The absence of a systematic approach to assess potential sites for solar power plants using Geographic Information System (GIS) technology poses obstacles to the efficient and effective harnessing of solar resources in the nation (Sharma *et al.*, 2021). Without a well-defined methodology, stakeholders involved in the renewable energy sector struggle to identify optimal locations that balance solar resource potential, minimize environmental impacts, and optimize grid connectivity (Benasla *et al.*, 2019).

Furthermore, the absence of a robust GIS-based framework limits the ability to align solar power plant installations with Kenya's renewable energy goals and targets. The failure to harness the full potential of solar energy hampers the country's transition towards a renewable energy future and hinders the diversification of its energy mix, heavily reliant on fossil fuels. Therefore, there is a pressing need for a comprehensive study that addresses these challenges by developing a GIS-based approach to assess suitable locations for photovoltaic solar power plants in Kenya.

This study aimed to provide a systematic methodology that incorporated relevant spatial data, such as solar radiation, slope, land use, infrastructure, and environmental factors, to enable stakeholders to make informed decisions regarding site selection. By bridging the gap between renewable energy goals and site suitability analysis, this research contributed to the sustainable development of Kenya's energy sector and support the country's transition towards a cleaner and more resilient energy system. Kenya has immense prospects for solar energy utilization due to its strategic position on the equator receiving solar radiation levels of 4-6kWh/m^2/day (Charles, 2013).

1.4. Objectives

The overall objective of this study was to use GIS in assessing ideal sites for solar power installations using Kajiado County as a case study. This research pursued several specific objectives which answered the research question.

Specific Objectives

a) To assess climate-resilient factors for solar power plant viability.
b) To identify data collection constraints for climate-adaptive PV solar plants.
c) To conduct climate-informed GIS analysis for solar PV system installation in Kajiado County.

1.5. Justification for the Study

According to a report by Kenya Power, the current energy demand in Kenya is approximately 2,056.67 MW. However, projected energy demand estimates indicate that by 2030, the demand is expected to be 5,000MW (Kenya Power, 2022). Kenya has set ambitious renewable energy goals, and solar power plays a crucial role in meeting these targets. As of now, only 1% of the energy demand in Kenya is being met through solar power (Longa *et al*., 2017). However, with the continued development and expansion of solar power infrastructure, it is projected that this percentage will increase to 10% in the coming years. The development of photovoltaic solar power plants in Kenya significantly contributes to achieving the country's renewable energy goals and reducing dependence on fossil fuels (Bishonge *et al.*, 2020). It also helps mitigate climate change and reduces Kenya's carbon footprint due to being environmentally friendly hence aligns with global policies such as the Paris Agreement, which aims to limit global warming to well below 2 degrees Celsius. Kenya is dedicated to realizing the Sustainable Development Goals (SDGs), with a specific emphasis on Goal 7, which strives to secure access to affordable, reliable, sustainable, and modern energy for everyone. Solar power plants contribute to clean and affordable energy access, thereby supporting Goal 7 (Jayachandran *et al*., 2022).

The availability of suitable land for solar power plant installation varies across different regions of Kenya due to variations in land characteristics and land use patterns. Factors such as land topography, land ownership, and existing land uses can influence the feasibility of solar power plant installation. These may include land zoning regulations, protected areas, ecological sensitivities, and cultural heritage sites. Geographic Information System (GIS) technology plays a vital role in identifying areas with minimal conflicts and optimal land use for solar installations. GIS enables the analysis of spatial data, including land use maps, topographic information, and environmental datasets, to identify suitable sites for solar power plants based on factors such as land availability, solar resource potential, proximity to infrastructure, and adherence to land use regulations. By integrating these spatial considerations, GIS helps decision-makers identify the most suitable locations for solar power plants, optimizing land use while minimizing environmental and social conflicts (Ndukwe *et al*., 2021). Spatial analysis enables decision-makers to identify areas suitable for solar power plant installations, maximizing energy generation and efficiency while accounting for variations in solar radiation intensity throughout the country (Gallego *et al*., 2019).

The creation of solar power plants utilizing photovoltaic technology in Kenya brings numerous socio-economic benefits. Firstly, it creates job opportunities in construction, installation, operation, and maintenance, contributing to local employment and skill development. Secondly, solar power plants promote local economic development by attracting investment and stimulating related industries. Additionally, solar energy projects enhance access to electricity in rural areas, where electrification rates may be lower, thereby improving living standards and enabling opportunities for education, healthcare, and economic activities. GIS plays a crucial role in assessing potential environmental impacts of solar power plants by analyzing spatial data on habitat distribution, water resources, and visual landscapes (Beata *et al*., 2020).
It enables the identification of potential areas of concern, such as habitat fragmentation or excessive water usage, and helps in identifying mitigation measures or alternative locations that minimize negative environmental effects, ensuring sustainable development and minimizing ecological disruptions.

This research aimed to fill gaps in the process of developing clean energy strategies in Kenya. In this regard, the study methodology had the following features:

a) The procedure was less costly compared to the conventional methods.
b) The process was less time consuming.
c) The procedure realistically presented the data collected.
d) The procedure was environmentally friendly
e) Data collection was conveniently stored and accessed easily for analysis and presentation.

The study further narrowed down to Kajiado County as a case study due to the following according to (Kajiado County Government website, 2019).

a) The county is arid and semi-arid region which receives enough solar radiation and high relative surface temperatures suitable for the construction of solar power plant.
b) The high increase of motorcycle taxis, vehicles and industries within the county and the surrounding counties which majorly operate with power generated from fossil fuels and

increase the emission of climate pollutants therefore the region requires renewable energy sources for a better future.

c) The overreliance on the conventional ways of identifying renewable energy source's locations which are costly, time consuming and unverifiable.

1.6. Scope and Limitation of the Study

The primary emphasis of the research study was on identifying appropriate sites for implementing photovoltaic solar plants in Kajiado County to harness solar energy. The research had certain constraints. Initially, the accuracy of the Global Horizontal Irradiance data collected through remote sensing methods could have been improved by incorporating field measurements. Furthermore, the study's approach involved jointly weighing the site suitability factors instead of evaluating them separately. Lastly, cultural factors were not taken into account during the analysis of site suitability, which solely focused on technical, economic, and environmental aspects.

Table 1 highlights some of the encountered risks and how they were mitigated during the study period.

Table 1: Risks and Mitigation Measures for the study.

No.	Risk	Mitigation Measures
1	Heavy prolonged rains in some sub-counties that would affect the programmed activities	The team were shifted to other areas with less rain and later come to these zones after the rains.
2	Jointly weighing site suitability factors	A multi-criteria decision approach was used to assign specific weights to each factor based on its significance.
3	Insecurity	We liaised with County Commissioner and other Government Security Agents.
4	Insufficient or inaccurate data may have affected the quality and reliability of the assessments	Obtaining reliable data was prioritized from reputable sources such as governmental agencies, satellite imagery providers, and local surveys. The data was validated and cross-referenced to ensure accuracy. Field surveys were conducted to collect missing or outdated information.
5	Neglecting cultural factors	The local communities and stakeholders were engaged to understand cultural preferences and concerns related to solar power plant installation.
6	Working with Geographic Information Systems (GIS) may have posed technical difficulties, including software compatibility issues, data processing limitations, or system failures	Compatibility between different tools and software used in the project was ensured. The researcher had a backup plan and regular data backups to prevent data loss. Trained team members adequately on GIS techniques and troubleshooting.
7	Inaccurate financial assessments, unexpected cost overruns, and changes in market conditions impacted the study's financial viability.	A comprehensive financial analysis considering factors such as capital costs, operation and maintenance expenses, solar resource variability, and potential revenue streams was conducted. Sensitivity analyses were performed to assess the study's resilience against various market scenarios.

CHAPTER TWO: LITERATURE REVIEW

2.1. Climate-Resilient Factors for Solar Power Plant Viability

Climate resilient factors for solar plant viability refer to the characteristics and strategies incorporated into the design, operation, and maintenance of solar power plants to ensure their ability to withstand and adapt to various climatic challenges and changes. These factors are essential for enhancing the sustainability, efficiency, and longevity of solar installations in diverse environmental conditions. A study by Gupta and Sharma (2022) highlighted the importance of solar power plant designs that can adapt to variations in solar irradiance. Their research emphasized the need for efficient tracking systems to optimize energy capture in fluctuating weather conditions. Wang and Zhang (2022) delved into adaptation strategies for solar power plants in the context of changing climate patterns. Their research highlighted the importance of flexibility in system designs and the incorporation of climate data into long-term planning using an ultra-short-term PV power forecasting method. The findings indicated that the power output from photovoltaic (PV) systems exhibits fluctuations that are both random and periodic, attributed to the movement of clouds and the daily variations in sunlight.

Li *et al*. (2022) addressed the significance of water management strategies in arid or water-scarce regions. Their study highlighted how efficient cooling systems, such as dry cooling or advanced cooling technologies, contribute to climate resilience by reducing water dependency. Liu *et al.* (2021) examined the role of energy storage systems in enhancing the resilience of solar power plants during intermittent weather conditions. Their findings emphasized the importance of efficient grid integration and storage solutions to ensure a reliable power supply. Climate-resilient approach to solar power plant viability involves a multifaceted consideration of solar irradiance patterns, temperature effects, extreme weather events, water management, material durability, policy support, and grid integration. In this study, the researcher consulted experts from various fields to determine these factors as they are essential for ensuring the sustainability and effectiveness of solar energy as a climate-resilient power source.

2.2. Data Collection Constraints for Climate-Adaptive PV Solar Plant

The efficient functioning and adaptability of PV solar plants in response to climate change rely heavily on accurate and timely data collection. Several challenges and constraints have been identified in recent literature, emphasizing the critical need for overcoming these barriers to enhance the climate resilience of solar power systems. Advancements in remote sensing technologies have offered valuable insights into solar resource assessment. However, a study by Zhang *et al*. (2020) have identified challenges related to the deployment, calibration, and maintenance of remote sensing equipment, impacting the consistency of data collection. Microclimate data is essential for understanding localized variations in solar conditions.

Recent research by Li *et al*. (2021) underscored the importance of microscale meteorological observations and acknowledges challenges in capturing fine-scale climate data for effective climate adaptation in solar plants. Ensuring the quality and standardization of collected data remains a persistent challenge. The study by Martinez-Hernandez *et al*. (2020) explores issues related to data quality and the lack of standardized metrics, emphasizing the need for consistent and comparable data for climate-adaptive measures. The availability and accuracy of weather data are crucial for predicting solar irradiance and temperature patterns. Sengupta and Barik (2021), have highlighted challenges in obtaining comprehensive and reliable weather data, hindering the precision of climate-adaptive strategies. Addressing these constraints requires ongoing research and technological innovations to ensure the availability and reliability of data critical for optimizing solar power plant performance in changing climatic conditions.

2.3. Climate-informed GIS analysis for solar PV system installation

Study by Pravalie *et al*. (2019) emphasized the significance of accurate solar resource mapping using GIS. The study focused on the assessment of Solar Energy Potential and Generation of Solar Maps. The integration of climate data enhances the precision of solar energy potential assessments. The results showed that advancements in the precision and reliability of solar energy potential assessments through GIS is of great importance, particularly when informed by climate data. These outcomes contribute to more accurate site suitability analyses but also provide a foundation for climate-resilient solar energy planning and decision-making. Geographic Information System (GIS) is extensively employed for analyzing site suitability. Research by Kircali and Selim (2021) looked into the Site Suitability Analysis for Solar Farms Using GIS and AHP in Turkey, it demonstrated the integration of climate factors into GIS-based decision-making for solar farm locations. The results influence solar farm planning practices in Turkey by providing insights into the integration of climate factors into GIS-based decision-making. The outcomes extend beyond site suitability analysis, impacting sustainability, resilience, and policy considerations for solar energy development in the region.

Lamya and Leena (2021) used GIS to assess Solar Photovoltaic Energy Potential in Saudi Arabia, the study employed GIS to model solar energy potential, considering climate factors such as temperature and solar radiation. The results provide a general overview of the potential outcomes based on assessing solar PV energy potential in Saudi Arabia using GIS and considering climate factors. In urban settings, GIS plays a vital role in mapping solar potential. Nevat *et al*. (2021) provided insights into GIS methodologies for assessing solar potential in urban environments, incorporating climate-informed data. The results provide a holistic understanding of solar potential in urban environments, incorporating climate-informed data to support sustainable and resilient urban energy planning. LiDAR technology combined with GIS enhances the accuracy of solar potential assessments. A study by (Tiwari *et al.*, 2020) showcased the use of LiDAR and GIS for precise solar potential mapping. The result shows a comprehensive and precise understanding of solar potential mapping, integrating LiDAR, GIS, and climate-informed analysis.

2.4. Multi-criteria Decision Analysis (MDC)

Multi-criteria Decision Analysis (MCDA) is a methodology used to evaluate and compare alternatives based on multiple criteria or factors. It offers an organized method for decision-making by considering various dimensions simultaneously, thereby facilitating a more comprehensive and informed decision. MCDA has found applications in numerous fields, including business, engineering, environmental management, and public policy (Wang *et al*., 2009). The study conducted by Suh *et al*. (2016) highlights the significance of GIS in evaluating variables such as air temperature, terrain slope, solar radiation, connection costs to the grid, and social and environmental restrictions when determining attractive locations. Decision-makers commonly participate in the assessment of factors deemed most critical for the installation of PV solar power using Multiple Criteria Decision Analysis (MCDA). Subsequently, the outcomes are applied within Geographic Information Systems (GIS) as weighting factors to identify appropriate sites for PV solar plant placement. Studies by Colak *et al*. (2020) and (Guhen, 2021) have carried research on assessing suitable areas for PV solar plants installation using the AHP method.

MCDA involves a systematic process that typically includes the following steps: problem identification, criteria selection, alternative generation, criteria weighting, evaluation, and final decision-making. In the problem identification phase, the decision context and objectives are clearly defined. Criteria selection involves identifying the relevant factors that will be used to evaluate the alternatives. Alternative generation focuses on generating a comprehensive list of potential solutions or options. During the criteria weighting phase, the significance or priority of each criterion is established. The assessment phase entails evaluating each alternative against the chosen criteria, typically employing mathematical models or decision support tools. Ultimately, a decision is reached based on the evaluation results, taking into account the weighted criteria and the decision-maker's preferences (Huang *et al*., 2011).

MCDA offers several benefits over traditional decision-making approaches. It allows decision-makers to consider multiple criteria simultaneously, providing a more comprehensive and balanced perspective. The systematic nature of MCDA helps in structuring complex decision problems and encourages transparency and consistency in the decision-making process. Moreover, MCDA permits the integration of both quantitative and qualitative elements., accommodating diverse types of information.

Various MCDA methods and techniques have been developed to support decision-making processes. Here are brief descriptions of some commonly used MCDA techniques and examples of studies that have utilized them:

a) Analytic Hierarchy Process (AHP): AHP is a methodical approach to decision-making that includes pairwise comparisons of criteria and alternatives to ascertain their relative significance. Arslan and Turan (2018) employed AHP in their research to assess potential locations for offshore wind farms, taking into account environmental, social, and economic criteria.

b) Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS): TOPSIS computes the relative proximity of alternatives to the ideal solution through comparisons of their distances to positive and negative ideal solutions. A research conducted by Kahraman *et al*., (2010) utilized TOPSIS to identify the most suitable renewable energy source in Turkey, taking into consideration economic, environmental, and social criteria. The study provided insights into the relative significance of the criteria weights in the decision-making process.

c) Preference Ranking Organization METHod for Enrichment Evaluations(PROMETHEE): PROMETHEE allows for comparing and ranking alternatives based on multiple criteria. A study by (Guan *et al*., 2019) used PROMETHEE to assess the sustainability of different electricity generation technologies, considering costs, greenhouse gases and community impact dimensions. The study indicates the relative importance of the dimensions in the overall sustainability assessment. Understanding the weight assigned to each dimension inform policymakers on where to focus efforts for improvement.

d) Simple Additive Weighting (SAW): SAW assigns weights to criteria and calculates a score for each alternative based on the sum of weighted criterion values. A study by Ma and Liu (2019) employed SAW to evaluate the suitability of different sites for solar power plant installation, considering economic, technical, and environmental factors. The study reveal the relative importance of weights assigned to the factors in the decision-making process which leads to identification of specific sites that are deemed optimal for solar power plant installation based on the combined evaluation of factors.

2.5. Analytic Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a method for multi-criteria decision-making that was developed by Thomas Saaty in the 1980s. It offers a systematic approach to assess and prioritize alternatives in complex decision scenarios. AHP involves decomposing a decision problem into a hierarchical structure comprising criteria and alternatives (Giovanni *et al*., 2010). This hierarchy typically comprises three levels: the goal, criteria, and alternatives. The goal represents the overarching objective or purpose of the decision, criteria are the factors or dimensions to be considered when evaluating alternatives, and alternatives are the potential courses of action or options under consideration (Saaty, 1987).

The AHP process begins with establishing the hierarchy and defining the decision problem. Decision-makers identify the goal and break it down into a set of criteria that are relevant to the decision context (Madjib *et al*., 2016). The criteria should be mutually exclusive and collectively exhaustive, covering all important aspects of the problem. Next, decision-makers compare the criteria pairwise to determine their relative importance or priority. This is done using a scale that represents the decision-maker's preferences, typically a numerical scale ranging from 1 to 9, where 1 indicates equal importance and 9 represents extreme importance (Vaidya *et al*., 2006).

Saaty Ration for Pairwise comparison

The Saaty Scale, also known as the Saaty Ratio or the Analytic Hierarchy Process (AHP) scale, is a method used for pairwise comparison in decision-making. It was developed by Thomas L. Saaty, (1987) to help prioritize and evaluate different criteria or alternatives based on their relative importance. The study developed a Saaty Scale consisting of a series of values that represent the intensity of importance of one element over another as presented on Table 2. The scale is a 9-point ratio scale, where each value corresponds to a level of preference.

Table 2: Fundamental Scale

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two elements contribute equally to the property
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An element is strongly favored and its dominance is demonstrated in practice

Intensity of importance	Definition	Explanation
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2, 6, 8	Intermediate values between two adjacent judgments	Compromise is needed between two judgments
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Source: Saaty, 1987

After establishing the criteria weights, decision-makers move to the next level of the hierarchy, which involves evaluating the alternatives against each criterion. Pairwise comparisons are again used to determine the relative performance or preference of the alternatives for each criterion (Madjib *et al.*, 2016). The decision-maker assesses how much one alternative is preferred over another using the same numerical scale. These pairwise comparisons generate preference matrices that are used to calculate the relative weights of the alternatives for each criterion.

The AHP combines the criteria weights and the alternative weights to calculate an overall priority or preference score for each alternative. This is achieved through a mathematical process called the eigenvector method. The eigenvector represents the priorities or weights of the criteria or alternatives, considering both the pairwise comparisons and the consistency of the judgments made by the decision-maker.

2.6. Energy Sector in Kenya

Ministry of Energy (MoE) oversees the Kenyan energy sector. The Electricity Regulatory Board (ERB) which was replaced by the Energy Regulatory Commission (ERC) regulates the entire energy sector of the country, following the cancellation of the Electric Power Act of 1997 and the successive ratification of the energy Act 2006. Other principals in the energy industry are: Kenya Electric Transmission Company (KETRCO) which controls the transmission grid development, Kenya Power and Lighting Company (KPLC) in control of vending with distributing power to consumers everywhere in the country, Geothermal Development Company (GDC) controls geothermal exploration and thermal drilling and production, Rural Electrification Authority (REA) controls the government's Rural Electrification programme, Independent Power Providers (IPP) investors in selling and producing electric power to KPLC and Kenya Electricity Generating Company (KenGen) controls electric power production. Energy and Petroleum Regulatory Authority (EPRA) is responsible for implementation, development, planning and execution of structures for renewable energy development (Ayhan *et al*., 2017).

The development of new, clean and affordable energy sources in Kenya is done to expand power supply and to displace polluting and expensive energy produced by both fuel oil and diesel power plants.

Today, the Lake Turkana Wind Power Plant is the largest wind farm on the African continent (Nina, 2021). The project was initiated in 2011 by Norfund which later sold all its shares to the Anergi Group in 2021. The wind Power Plant consist of 365 wind turbines and high voltage substations. The 50MW Garissa Solar Power Plant is the largest grid connect solar power plant in East and Central Africa (Chisika *et al*., 2021). The project is promoting the development of sustainable, reliable, clean and affordable energy to the country.

It is therefore important to create and utilize a cost effective and environmentally friendly decision-making system in order to develop timely corrective measures that are within the cost limitations. This research lays emphasis on the need to utilize GIS in clean energy development in Kenya and further presents system structure development procedures of a GIS based decision making procedure that will enhance renewable energy development in the country (Klagge *et al*., 2020).

.

2.7. The Photovoltaic Systems

The procedure for assessing suitable locations for PV solar plants using GIS is outlined in Figure 1. PV systems consist of solar panels mounted on posts erected on ground or installed on the rooftop. An electric current is generated when the sunlight hits on the photovoltaic cell. The process involves the movement of electrons to create an electric charge that can energize the load. The PV systems are highly durable and require little maintenance due to the absence of any moving parts. In addition, the PV systems are very economical especially the ones in the remote areas since no supplementary energy source is required to run the systems.

PV systems are generally categorized into two main types: Grid-connected and Off-grid systems. A Grid-connected PV system serves as a solar electricity generator for homes or small businesses throughout all seasons, being linked to the utility grid. Any surplus electricity generated is returned to the grid.

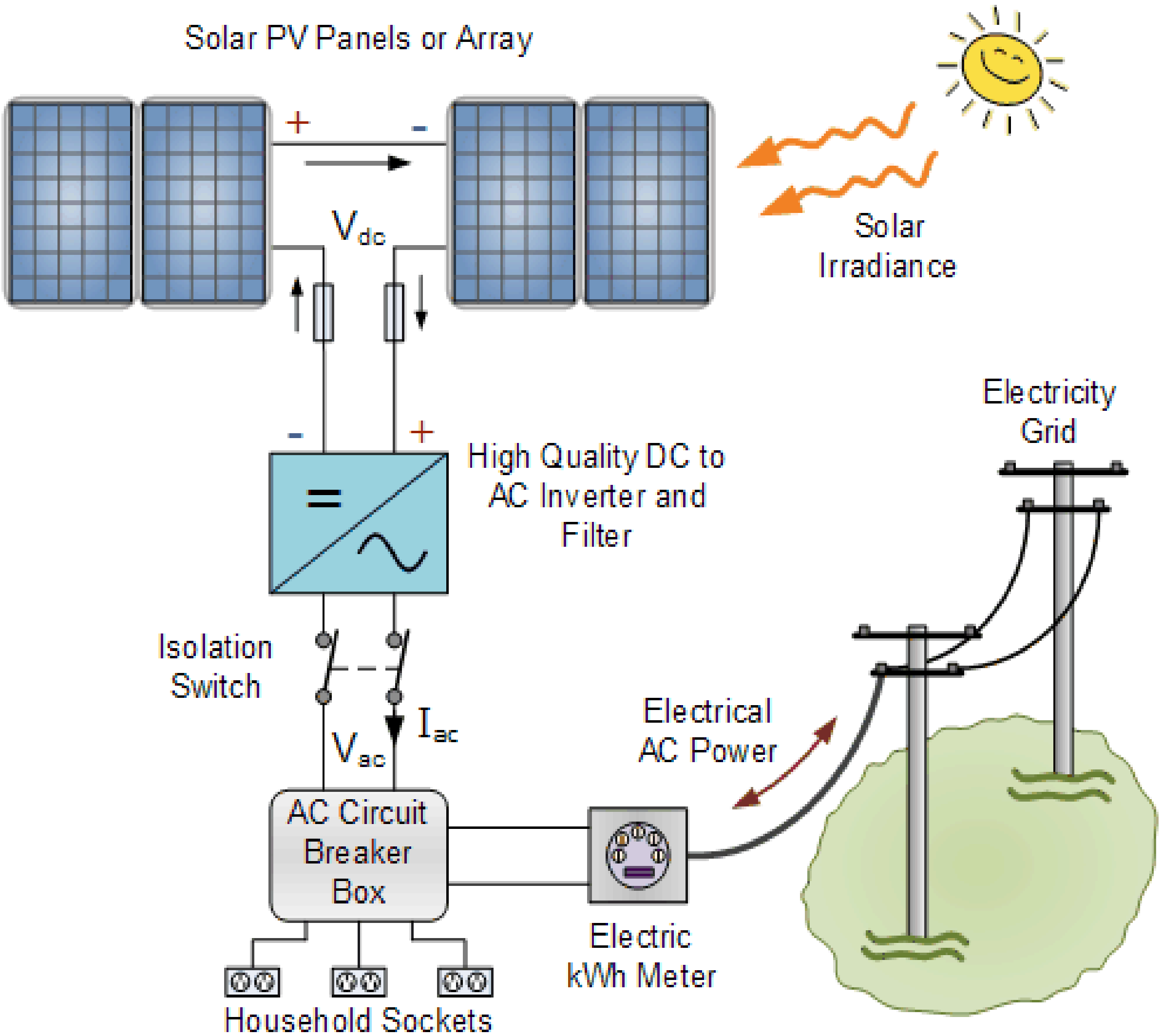


Figure 1: Grid connected PV system
Source: (Alternative Energy Tutorials, 2021)

The Off-grid PV system has no public electricity grid as presented on Figure 2. The battery stops receiving power from the solar system once it is full. It consists of PV modules, batteries that stores power that is used when the sun goes down, a charge controller that controls the charging system and inverter for transforming AC current from DC current.

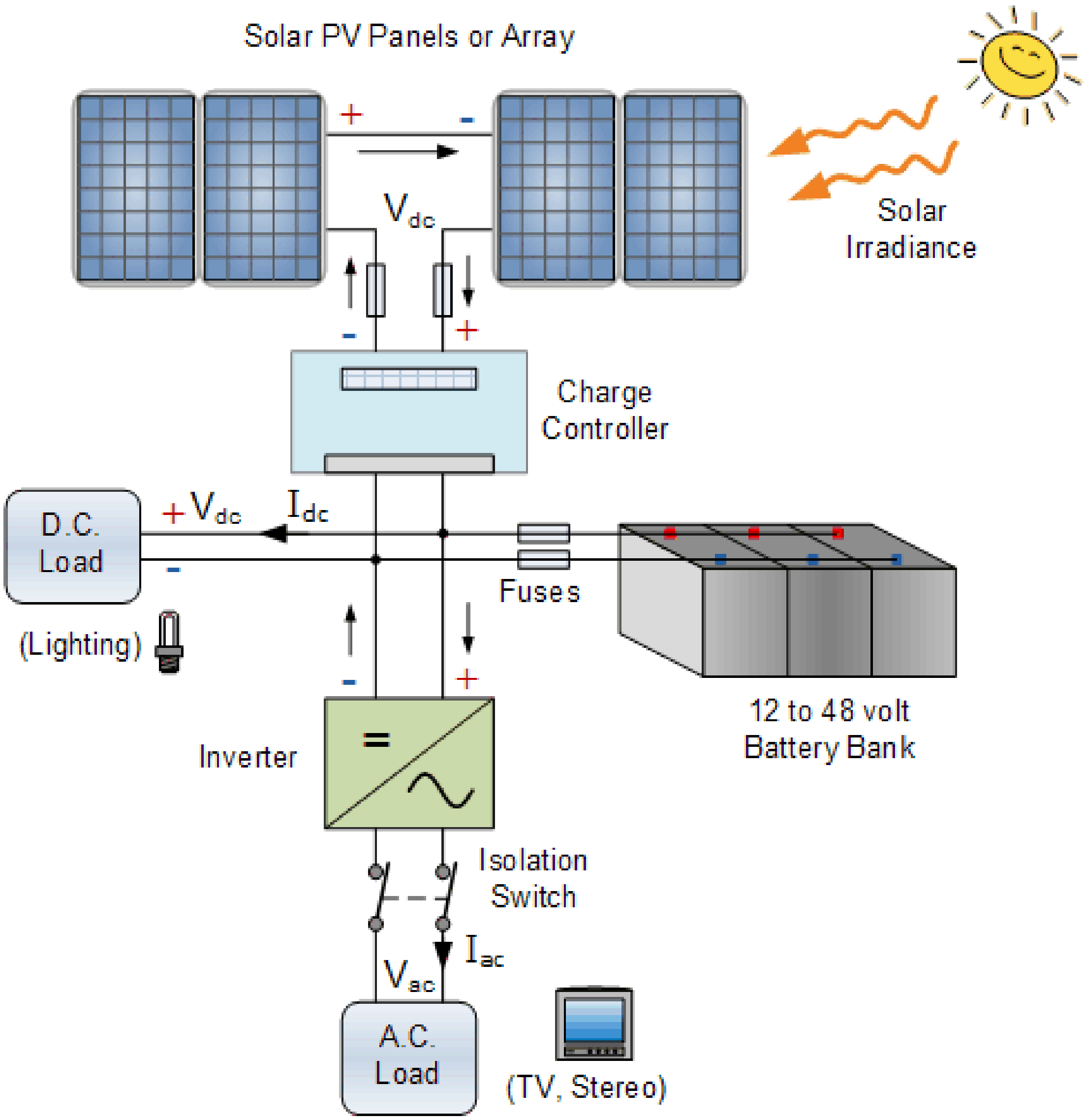


Figure 2: Off grid (Stand Alone) connected PV system
Source: (Alternative Energy Tutorials, 2021)

2.8. PV Systems Siting Criterion

The selection process of PV systems siting is impacted by several factors. These factors were categorized into environmental factors for conservation purposes, economic factors and efficiency/technical factors.

2.8.1. Environmental Factors

The environmental factors considered for this study were as follows;

a) **Land Use Land Cover (LULC) –** Land use land cover refers to the classification and utilization of land areas. It is an environmental factor as it assesses the existing land cover types, such as forests, agricultural land, urban areas, or protected areas. Evaluating land use land cover helps identify areas where solar power plants can be installed without significant environmental impacts (Campell *et al*., 2017).

b) **Soil Type –** Soil type is an environmental factor as it affects the foundation and stability of solar power plant infrastructure. Certain soil types may require additional engineering or soil stabilization measures, which can have environmental implications. Soils with high permeability and good drainage properties are ideal for solar installations. Adequate drainage prevents waterlogging and helps maintain the integrity of the solar infrastructure (Castillo *et al.*, 2016**)**.

2.8.2. Economic Factors

The economic factors selected for this study includes, distance from roads.

a) **Distance from roads -** Distance from roads is an economic factor as it influences the cost of construction, transportation, and maintenance. Locations closer to existing road infrastructure are generally more cost-effective for solar power plant development (Gorbunov *et al*., 2019).

2.8.3. Efficiency/ Technical Factors

In this study, the technical factors are the major criteria that were focused on.

a) **Slope** –Flat land is ideal for building solar power plants as it receives higher solar radiation than areas with slightly higher gradient (Doorga, 2019). The slope of the land can impact the orientation and tilt angle of the panels, affecting their energy capture and performance.

b) **Solar Radiation** –Solar irradiance is the key factor for building solar power plants. Regions with high radiant energy are considered suitable for siting the PV plants. It is crucial to assess the solar radiation levels in a given location to determine its suitability for solar energy generation (Garni *et al*., 2017).

2.9. Conceptual Framework

This study aims to assess suitable locations for PV solar power plants in Kajiado county using GIS with a focus on climate resilience. Existing literature indicates a gap in the consideration of climate-resilient factors during the installation of PV solar plants. In their examination of the suitability of sites for solar PV power generation in South Gondar, Nebey *et al*., (2020) performed an evaluation; however, the study did not take into account climate-resilient factors in the installation of the solar infrastructure. Figure 5 shows an illustration of conceptual framework as per this study. Suitable metrics for assessing PV site suitability were identified, which were categorized as economic, technical, and environmental criteria. Under economic factors distance from roads, under technical factors, solar radiation and slope, under environmental factors soil type and Land use. The metrics were weighted using the analytical hierarchical process as presented. The data processing involved creating raster layers from the vector data and conducting terrain analysis to determine the slope of the study area. Ultimately, the raster layers were overlaid to determine the final suitable locations for PV solar power plant installations.

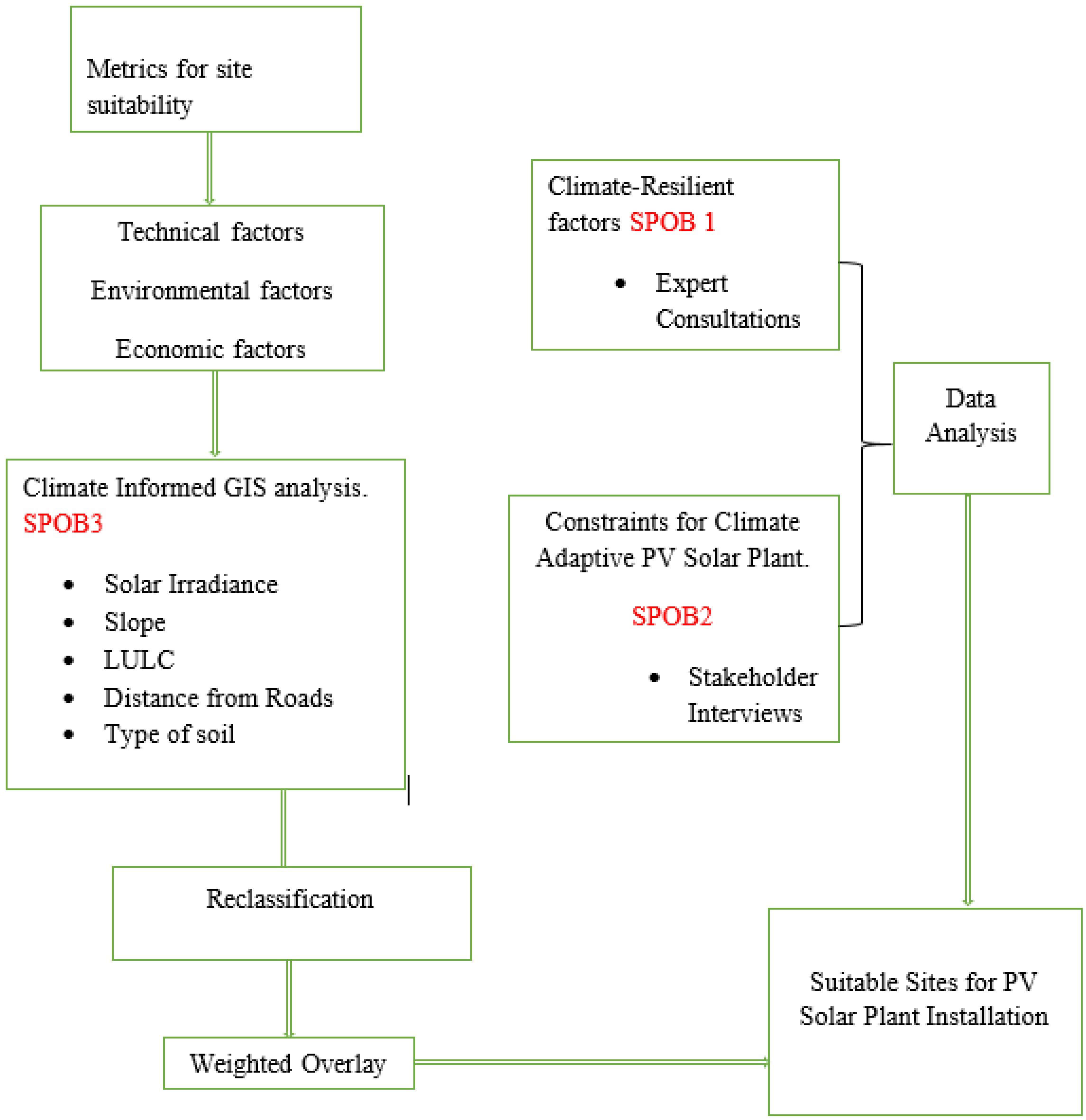


Figure 3: Conceptual Framework of the study. Where SPOB 1, SPOB 2 and SPOB 3 stand for specific objective 1, 2 and 3 respectively.

CHAPTER THREE: MATERIAL, DATA AND METHODOLOGY

3.1. Study Area

Kajiado County is located in the Rift Valley region part of Kenya. It borders the counties of Nairobi, Narok, Nakuru and Kiambu. It further acts as a border county to Tanzanian regions of Arusha and Kilimanjaro as depicted on Figure 4. Kajiado county is a semi-arid region and one of the driest counties in Kenya with typically varying temperatures from 12℃-28℃ over the course of the year (Kajiado County Government website, 2019).

Figure 4: Kajiado County Map

The main economic activity in Kajiado County is pastoralism, livestock rearing and crop farming with crops grown ranging from beans, maize, millet, bulb onions, sorghum and cassava which is majorly cultivated by irrigation. Farmers incur huge losses due to drought and construction of a solar power plant will be of great importance as solar powered tools require minimum water delivery to the crops. There is need to optimize the high solar radiation of 2000KWh/m^2 per annum of the region prioritizing well-being of the residents by initiating green energy (Obasi *et al*., 2015).

The capacity to imagine and conceive the development of solar PV systems facilitates the prioritization and crucial decision-making of projects. A Geographic Information System (GIS) platform empowers green energy planners and project managers to visualize, analyze, and comprehend data in relevant trends and patterns by utilizing maps and graphs. This research intends to integrate GIS technology to help energy and climate change experts easily make better decisions on future installation of solar PV systems so as to effectively plan and implement construction processes.

3.2. Data Description

Primary data were collected using a mobile mapper. The gadget was mounted on a moving vehicle, collecting slope, distance from roads, land use land cover and type of soil data as it moved across the study area. The datasets collected were obtained in real-time. This data was used to validate the secondary data used in this research. The table below provides a summary of the utilized secondary data. Solar irradiance data, obtained from the World Bank with a 1km resolution, was utilized to extract annual solar radiation for the study area. The digital elevation model, sourced from the USGS Earth Explorer portal, was employed to calculate the slope of the study area at a 90m resolution. Soil information, with a spatial resolution of 1km, was retrieved from the Kenya Soil and Terrain database (KENSOTER). Road data from KRB was used to create distance raster layers from roads. Land use and land cover datasets, obtained from the National Environment and Management Authority, were employed to generate exclusion raster. All datasets were collected for a one-year duration corresponding to the year 2022. Vector-format datasets were converted to raster format using the standard tool in ArcGIS 10.4.1.

Table 3: Summary of used data, source, duration and their resolution.

S/ NO	DATA	SOURCE	DURA-TION	RESOL-UTION	DATA FORMAT
1.	Solar irradiance	World Bank (https://data.worldbank.org/)	1 year	1KM	Raster format
2.	DEM	USGS Earth Explorer portal (https://www.usgs.gov/)	1 year	90M	Raster format
3.	Soil	KENSOTER (http://www.landscapesportal.org/layers/geonode:kensoter)	1 year	1KM	Raster format
4.	LULC	NEMA https://www.nema.go.ke/	1 year	N/a	Vector format and converted to Raster format
5.	Roads	KRB https://krb.go.ke/	1 year	N/a	Vector format and converted to Raster format

3.3. Training of Project Resource for the collection of primary data.

The data collection task under this research not only necessitated the coverage of a large and diverse areas around Kajiado County, but also required the reliable collection, verification and transmission of large amounts of network inventory and condition data.

Before data collection process began, the data collection teams were thoroughly trained so that all the team members had a common understanding on what was to be done. The training covered data logging procedures, data analysis, evaluation and validation. The team were taken through data collection methodology and procedures and acquainted with the use of the survey equipment to collect the required data. Data collection team were also trained in the proper maintenance and use of notebook computers, GPS equipment and software, data storage and retrieval and data transmission to the researcher.

3.4. Primary Data Collection Procedure Using Mobile Mapper

The Mobile Mapper 50 device as show on Figure 5 is a modern age GIS data collection device running on an Android interface that offers state of the art capabilities combined with cutting edge professional quality and improved GNSS performance (Ciecko *et al.*, 2020). It is lightweight, compact, waterproof and unique in being a professional grade data collection device. It offers accurate Global Navigation Satellite System (GNSS) which is a satellite-based positioning technology used to determine the geographic coordinates (latitude, longitude, and sometimes altitude) of a mobile mapping device as well as post processing ad ones (Nowak *et al*., 2020)

The mobile mapping system, was fixed to a moving vehicle, it incorporates diverse instruments such as cameras, LiDAR (Light Detection and Ranging), and GPS (Global Positioning System). The device facilitated the collection of real time data for distances from roads, slope gradients, land use and land cover details, and soil types as it traversed the environment. The sensors employed in this process were utilized to measure and record these various parameters. This data was compared with the data in Table 3 to validate the secondary datasets used in the research.

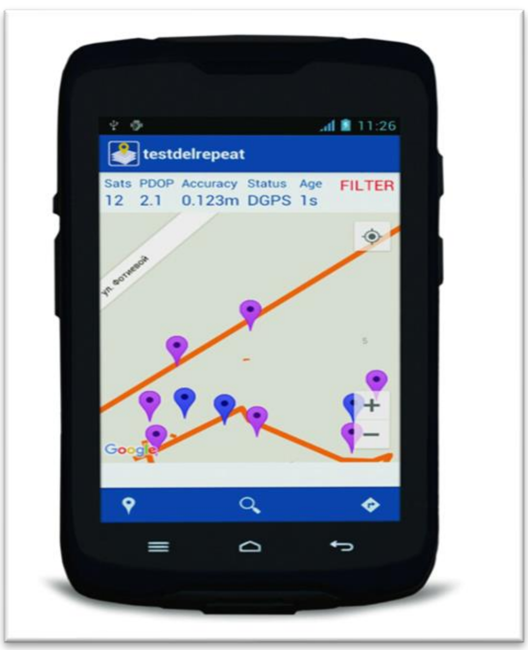


Figure 5: Mobile Mapper

3.5. Establishing Data Standardization and Integrity

Data dictionary is a centralized document that standardizes and documents the terminology, definitions, structure, and characteristics of data used in a project. It served to promote uniformity in the collection of data and facilitate the smooth uploading of collected data into a geodatabase. The objective of preparing a harmonized data dictionary was to promote uniformity of data to be collected and to facilitate smooth uploading of the collected data to the geodatabase. Furthermore, creation of Feature Classes with associated domains and sub-domains for use within the geodatabase that correspond to the above agreed data dictionary was conducted. In this way the integrity of the GIS information was ensured and consistent.

Data dictionary helped in standardizing the terminology and definitions used for different data layers and attributed within this study. It ensured consistency in the naming conventions, units of measurement, and data formats. This standardization improved data quality and reduced errors or confusion during data analysis and interpretation. It also served as a comprehensive documentation of the GIS project's data components. It provided detailed information about the meaning, source, and characteristics of each dataset and attribute. This study involved integrating data from various sources and formats. The data dictionary facilitated interoperability by describing the structure and relationships of different datasets. It allowed the understanding of how datasets can be combined or related to perform spatial analysis, queries, or data fusion accurately.

3.6. Geospatial Data Processing and Analysis using ArcGIS

The data acquired from the reliable sources mentioned in Table **3** was cleaned and processed to remove any outliers in raster format. Data processing encompassed coordinate transformation, wherein all datasets underwent projection and were assigned a consistent coordinate system. The selection of WGS 84, UTM Zone 37N aligns with the study area's location for accurate geographical representation and analysis. The use of a projected coordinate system facilitated accurate distance calculations. Additionally, raster conversion of vector data ensured uniformity for data analysis. ArcGIS software was opened; the base map of the study area was loaded to provide context for data used. The preprocessed data was imported into ArcGIS and the researcher ensured that the coordinate system of the data aligned with the base map. The raster calculator tool in ArcGIS was used to perform spatial analysis on the data then the weighted overlay tool was utilized to combine different layers of data, assigning weights to each layer based on their importance in determining suitability.

To assign weights to the solar radiation, slope, land use land cover, soil type and distance from roads criteria, the Analytical Hierarchical Process (AHP) was employed. These weights were subsequently utilized in the overlay analysis, resulting in the identification of potential PV site locations. The collected data was preprocessed to ensure compatibility and accuracy. The datasets were organized and prepared for integration with the GIS environment. This step ensured that all data layers were ready for analysis and interpretation. A suitability map was generated based on the results of the weighted overlay analysis.

3.7. Suitability Criteria Development

A set of suitability criteria was developed based on established guidelines and best practices in the PV solar industry (Noorollahi *et al*., 2022). These criteria included factors such as solar radiation intensity, slope, land use compatibility, proximity to infrastructure and type of soil. The criteria assigned weights according to their relative importance in determining suitability.

Solar Radiation Intensity: Solar radiation is a critical factor for PV solar plant performance. Areas with higher solar radiation levels were generally more suitable for solar energy generation. Factors such as cloud cover, altitude, and shading from surrounding objects are taken into account when assessing solar radiation intensity (Yan *et al*., 2017).

Slope: The slope of the land affects the efficiency of PV solar panels. Areas with moderate slopes were often preferred as excessively steep slopes may pose challenges for panel installation and maintenance. Additionally, the slope can influence the amount of sunlight received by panels and affect energy generation (Jen *et al*., 2022).

Land Use Compatibility: This criterion considered the existing land use patterns in the study area. Areas with minimal conflicts or restrictions related to land use, such as agricultural land, protected areas, or residential zones, were generally more suitable for PV solar plant installation. Compatibility with existing land uses ensures efficient land utilization and minimizes conflicts (Hernandez *et al*., 2015)

Proximity to Infrastructure: The proximity of a potential site to existing infrastructure plays a crucial role in determining its suitability. Proximity to road networks was considered. Sites closer to infrastructure can minimize costs associated with grid connection and access to essential services (Angel, 2009).

Environmental Sensitivity: The environmental impact of PV solar plant installation was carefully assessed. Areas with lower ecological sensitivity, such as avoiding habitats of endangered species, protected areas, or areas prone to erosion or flooding, are typically preferred. This criterion ensures sustainable development and minimizes adverse effects on the environment. Table 5 below shows classification of raster maps into different classes (Denis, 2016).

Table 4:Classification of raster maps into different classes of suitability and their description

Criteria	Classes	Description	Suitability	Source
Solar radiation	High	Areas with solar irradiance of < = 2000kWh/m^2 per annum	Suitable	(Pravalie *et al*., 2019)
	Moderate	Areas with solar irradiance of 1500 - 1900kWh/m^2 per annum	Moderately suitable	
	Low	Areas with solar irradiance of >1500kWh/m^2 per annum	Not suitable	
Slope	Gentle	Areas with less than 3% gradient	Suitable	(Colak *et al*., 2020)
	Moderate	Areas within 3%-7% gradient	Moderately suitable	

Criteria	Classes	Description	Suitability	Source
	Steep	Areas with greater than 10% gradient	Not suitable	
LULC	Agriculture	Areas primarily used for Agricultural purposes	Suitable	(Lin *et al*., 2021)
	Grassland	Areas covered by grass and open vegetation	Moderately suitable	
	Forest	Areas with dense forest cover	Not suitable	
	Urban	Areas with urban infrastructure and human settlements	Not suitable	
Soil type	Permeability Drainage properties Stability	Soils with high permeability and good drainage properties are ideal for solar installations. Soils with poor stability might not be suitable as they can cause settling and unevenness, leading to potential damage to the solar array over time.	Suitable Not suitable	(Formolli *et al*., 2022)
Distance from roads	500m-1000m	Areas within 500m-1000m distance from roads for infrastructure access	Suitable	(Nebey *et al*., 2020)
	1000m-1500m	Areas located within the distance of 1000m -1500m from the roads	Moderately suitable	
	Above 1500m	Areas located far from roads, posing challenge for infrastructure development.	Not suitable	

3.8. Assessing Climate-Resilient Factors for Solar Power Plant Viability

A panel of experts was identified by considering professionals with 5 years of experience in renewable energy and a background of expertise in climate resilience strategies (Olabi and Ali, 2022). The researcher reached out to professional networks and industry associates and a request for their participation in an interview to share insights on climate-resilient factors was made via email. The experts with the mentioned qualifications expressed their interest in the interview and a purposive sampling method was used to select the experts who participated in the interview (Campbell *et al*., 2020). A detailed information about the study, the interview process and the expected time commitment was provided. The problem was then clearly articulated for the experts to address. In this case, it was to assess the climate resilient factors to be considered when installing a solar PV plant for optimal performance and resilience. Discussions were conducted on this topic and this facilitated the exchange of ideas and allowed for consensus-building on climate resilience factors influencing the installation of solar PV plants ((Olabi and Ali, 2022). The responses from the experts were collected and analyzed. Common themes and factors mentioned by multiple experts were identified then a list of these factors was compiled. The responses were analyzed and the factors that received high rankings or consensus among the experts were identified. The results were summarized and the factors that received the highest consensus were highlighted.

3.9. Identifying data Collection Constraints for Climate-Adaptive Solar Plants

In the comprehensive assessment of constraints for climate-adaptive solar plants, a multifaceted approach was undertaken, leveraging stakeholder interviews and surveys to gain valuable insights from diverse perspectives (Silva *et al*., 2022). The research methodology aimed to capture the nuanced challenges and limitations faced by stakeholders involved in the planning, implementation, and operation of solar plants in environmentally dynamic regions.

The first phase involved targeted stakeholder interviews, where key individuals representing various sectors, including energy, environmental policy, local governance, and community engagement, were identified (Attia and Romain, 2020). A semi-structured interview format was employed to ensure a depth of understanding while allowing flexibility for participants to elaborate on specific issues. Interviews were conducted face-to-face and focused on soliciting firsthand experiences and perceptions related to the constraints associated with climate-adaptive solar plant initiatives.

The qualitative data gathered from interviews were meticulously compiled and organized. Thematic analysis was employed to identify recurring patterns, constraints, and emerging themes. The triangulation of data from multiple sources enriched the overall understanding of the constraints faced by climate-adaptive solar plants and enhanced the validity of the findings. To ensure the rigor and reliability of the study, an iterative process was adopted (Sengupta and Barik, 2021). This cyclical approach allowed for ongoing refinement of research questions and ensured that the data collected adequately addressed the complex interplay of factors influencing climate-adaptive solar plant initiatives. Throughout the research process, ethical considerations were paramount. Informed consent was obtained from all participants, and steps were taken to ensure the confidentiality and anonymity of respondents. The research adhered to ethical guidelines to protect the rights and well-being of stakeholders involved.

3.10. Suitability Criteria Assignment and reclassification of raster maps

The process of suitability criteria assignment and reclassification of data involved the comprehensive analysis of multiple factors crucial for solar power plant site selection, including solar radiation, slope, land use land cover, distance from roads, and type of soil. The first step involved defining specific suitability criteria for each parameter, considering their relevance to solar power plant viability. Subsequently, a meticulous reclassification process was undertaken, whereby each parameter's data were transformed into three distinct classes: suitable, moderately suitable, and not suitable. This classification aimed to categorize the study area based on its appropriateness for solar power plant installation, providing a nuanced understanding of the landscape (Kelvin, 2021). The assignment of these classes was likely determined through a systematic assessment, considering optimal ranges for solar radiation, slope gradients, land use types, proximity to roads, and soil characteristics. This reclassification facilitates a clearer visualization of site suitability, offering valuable insights for decision-makers involved in solar energy planning and infrastructure development.

3.12.1. Proximity Suitability Analysis

Proximity analysis, a technique employed within the Geographic Information System (GIS) framework, facilitated the identification of optimal solar power plant locations in relation to key features and distances within the project scope. This analytical approach involved assessing the proximity of potential sites to significant factors such as urban areas, roads, water bodies, and other sensitive features (Wong *et al*., 2016).

Specifically, GIS technology played a pivotal role in mapping and assessing the road network, which was a critical aspect of the proximity analysis. The GIS platform integrated spatial data related to road infrastructure, allowing for a detailed assessment of the distance between potential solar power plant locations and major roads. According to Nebey *et al*., (2020), regions distant from road infrastructure are economically unviable and unsuitable for solar PV. Consequently, sites within a distance of less than 500 m are designated as highly suitable, those within 500-1000 m are considered suitable, those within 1000-1500 m are classified as moderately suitable, and distances greater than 1500 m are deemed unsuitable.

Utilizing GIS functionalities, the proximity analysis considered the spatial relationships between candidate sites and various features, enhancing the selection process for suitable solar power plant locations. The methodology involved in-depth mapping and assessment of the road network, ensuring that areas in close proximity to major roads were prioritized as more favorable for establishing solar power plants.

The study by (Damon *et al.*, 2011) employed GIS-based proximity analysis to quantitatively evaluate the distances from crucial features, contributing to the identification of strategic locations for solar power plant installations. This approach enhances the decision-making process by systematically considering the proximity of potential sites to essential factors, optimizing the efficiency and feasibility of solar energy projects.

3.12.2. Terrain Suitability Analysis

Terrain analysis involves analyzing the characteristics of the terrain, such as slope, aspect, elevation, and topography, to assess its suitability for a particular purpose. In the case of the solar power plant project, terrain analysis was conducted using GIS technology to identify areas with optimal slope angles, which maximize solar exposure and energy generation potential. Flat or gently sloping areas were preferred for efficient installation and performance of solar panels. According to ((Nathan *et al*., 2022), Geographic Information System (GIS) technology is commonly used to analyze and map terrain characteristics. GIS allows for the integration of various spatial data layers, including DEMs, to perform spatial analysis. GIS tools facilitated the calculation of slope angles, determination of aspect, and generation of topographic map, providing a comprehensive understanding of the terrain's suitability. The outcome was a quantitative assessment of the suitability of different locations within Kajiado County for PV solar plant installation.

3.12.3. Solar Radiation Suitability Analysis

The feasibility of solar power plant installations is inherently linked to solar radiation, as highlighted by (Alhamad *et al.,* 2022). In this study, the researcher leveraged Geographic Information System (GIS) technology to conduct a spatial analysis of solar irradiance data, assessing the solar energy potential throughout Kajiado County.

The methodology involved the creation of a high-resolution solar radiation map using GIS tools. Through this spatial analysis, we systematically evaluated insolation levels across the county. The resulting solar radiation map served as a valuable resource, pinpointing areas with optimal exposure to sunlight for effective energy generation.

The GIS-based analysis allowed for a quantitative assessment of the solar energy potential, and the identification of high irradiance zones became a focal point in our suitability assessment. These zones, characterized by optimal solar exposure, were prioritized in our site selection process (Thad *et al*., 2019). The GIS approach not only facilitated the visualization of solar radiation patterns but also provided a robust foundation for objectively identifying areas with the greatest potential for efficient and effective solar power generation.

3.12.4. Soil Type Suitability Analysis

In our analysis, the assessment of soil characteristics was conducted using laboratory method with a focus on key factors such as texture, organic matter content, and drainage characteristics. This comprehensive soil analysis aimed to evaluate the suitability and stability of the soil for supporting solar power infrastructure, aligning with the findings of (Purohit *et al.,* 2013).

- **Texture Analysis:** Texture refers to the composition of soil particles, including the proportions of sand, silt, and clay. Soil texture influences water retention, drainage, and the load-bearing capacity of the soil. We conducted a thorough examination of soil texture to identify areas with compositions conducive to supporting the installation of solar panels and associated infrastructure. Suitable soil textures provide a stable foundation for solar infrastructure.

- **Organic Matter Content Assessment:** The organic matter content of soil is a critical factor influencing its fertility and structural stability. High organic matter content enhances nutrient availability and water retention, contributing to a more stable soil structure. Our analysis considered the organic matter content to identify areas with fertile and structurally sound soils, contributing to the overall feasibility of solar power infrastructure.

- **Drainage Characteristics Evaluation:** Efficient drainage is essential for maintaining soil stability, especially in the context of solar power infrastructure. Poor drainage can lead to soil erosion and instability. Therefore, we assessed the drainage characteristics of the soil to identify areas with well-drained soils, which are more suitable for supporting solar panels. Conversely, areas with inadequate drainage were pinpointed to avoid potential issues with stability.

The integration of these soil parameters into our analysis allowed us to highlight regions with suitable soil types for the installation of solar panels and associated infrastructure. By identifying areas with stable and well-suited soil characteristics, we contribute to the technical feasibility of potential solar power sites. Conversely, areas with unstable or unsuitable soil were deliberately avoided to mitigate potential challenges and ensure the long-term stability and success of the solar power infrastructure (Gambino *et al*., 2019). This approach aligns with best practices in site selection, considering soil conditions as a critical factor in the overall success of renewable energy projects.

3.12.5. Land Use Land Cover Suitability Analysis

The existing land use and land cover within Kajiado County were examined by first cleaning and preprocessing the collected LULC data to ensure consistency and compatibility. ArcGIS software was then utilized to set up a spatial database and to create workspace for integration of land use land cover data. The datasets were merged to create a comprehensive spatial representation of the existing land use and land cover. Land use classes were categorized based on their potential for solar energy development, these classes include: Protected areas, Commercial and built up areas, bare land, vegetation cover and water bodies. Agricultural and barren lands were prioritized due to their minimal land use conflicts and potential for repurposing (Nebey *et al*., 2020). Urban and environmentally sensitive areas were identified as less suitable, considering factors such as shading, regulatory restrictions, and ecological impact (Palme *et al*., 2020).

3.12.6. Weighted Overlays for Solar PV Suitability Analysis

The integration of criteria weights was achieved through the application of the ArcGIS 10.4.1 weighted overlay tool. The reclassified maps of solar irradiance, distance from roads, slope, soil type, and land use land cover, was overlaid using the weighted overlay tool in ArcGIS and a systematic approach was adopted, incorporating the Analytic Hierarchy Process (AHP) method for decision-making (Gambino *et al*., 2019). Initially, each criterion was reclassified to a common scale, ensuring consistency and comparability. Subsequently, the AHP method was employed to assign weights to each criterion based on their relative importance in the solar power plant site suitability analysis. The reclassified datasets were then spatially overlaid within a Geographic Information System (GIS) framework, employing a weighted overlay analysis. This involved multiplying each criterion's reclassified values by their respective weights and summing the products to derive an aggregate result for each location. The overlay process enabled the synthesis of multiple criteria into a comprehensive suitability map, providing valuable insights into the optimal sites for solar power plant installation, considering the diverse factors influencing viability in the study area (Guhen, 2021). The solar PV suitability ranged from one to three, leading to the categorization of the study area into three main suitability levels for solar PV placement.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Introduction

This chapter presents results and discussions on the identification of optimal PV solar power plants in Kajiado County. The integration of Geographic Information Systems (GIS) enabled a systematic evaluation of technical, economic and environmental factors, resulting in the identification of areas conducive to solar energy harnessing. This study considered climate-resilient factors to enhance the viability of solar power plants in adapting to varying climatic conditions. Employing a multifaceted approach, including stakeholder interviews and surveys, the study assessed constraints for climate-adaptive solar plants.

The analysis, driven by datasets comprising solar radiation, slope, land-use, distance from roads and type of soil, culminated in identifying several areas with strong potential for implementing photovoltaic solar power facilities. These locations were identified based on a composite suitability index, considering factors such as solar irradiance, slope, distance from roads, and land availability. Subsequent spatial analysis revealed distinct clusters of high and moderate suitability zones across the county.

4.2. Climate-resilient factors for solar power plant viability

The climate resilience of solar power plants hinges on factors that enhance the system's capacity to endure and adapt to diverse climatic conditions. The significance of these climate-resilient factors lies in their collective contribution to the viability and sustainability of solar power plants across varying environmental contexts. The implementation of a combination of these measures is acknowledged as a potential avenue to bolster the overall performance and longevity of solar power systems, rendering them more resilient to challenges posed by climate variability, this result is associated with a study by Ghadami *et al,* (2021). The study elaborates a potential avenue to enhance the overall performance and longevity of solar power systems in relation to climate resilience. A study Wang and Zhang (2022) delved into adaptation strategies for solar power plants in the context of changing climate patterns, the results aim to make solar power systems more robust and adaptable to challenges posed by climate variability.

After consulting with experts, the following were the findings. Associated with a study conducted by Liu *et al*. (2021), the study has found the climate-resilience factors to be of great importance when installing solar PV power plant.

- **Robust Solar Panel Design:** Durable materials and coatings were revealed to be used for solar panels to withstand extreme weather conditions such as hailstorms, high winds, and temperature fluctuations. This enhances the overall longevity of the solar panels.

- **Advanced Tracking Systems**: Solar tracking systems that can adapt to changing weather conditions were identified to be implemented. Dual-axis or smart tracking systems optimize the angle of solar panels to maximize energy capture during different times of the day and seasons.

- **Cooling Mechanisms**: Effective cooling mechanisms were established to be integrated to mitigate the impact of high temperatures on solar panel efficiency. This was found to include passive cooling techniques such as reflective coatings or active cooling systems like water or air circulation.

- **Weather-Resilient Inverters**: Weather-resistant inverters that can operate efficiently in a wide range of temperatures were concluded to be utilized. Inverters being critical components for converting DC electricity generated by solar panels into AC electricity for use in the grid.

- **Adaptive Grid Integration**: Designing solar power systems with grid integration features that can respond to fluctuations in energy production and demand was determined. Smart grid technologies and energy storage solutions help balance the intermittent nature of solar power generation.

- **Resilient Mounting Structures**: Sturdy and resilient mounting structures were suggested to be used to anchor solar panels securely to the ground. This was verified to be of great importance in areas prone to strong winds, heavy rainfall, or seismic activity.

- **Community Engagement and Education**: Involving local communities in the planning and maintenance of solar power plants was acknowledged. Educating community members about the benefits of renewable energy, climate resilience strategies, and emergency response plans in case of extreme weather events was suggested.

- **Energy Storage Systems**: Integrating energy storage systems, such as batteries, to store excess energy during optimal conditions for use during periods of low sunlight or high energy demand was discovered. This was found to help in maintaining a consistent energy supply even in adverse weather conditions.

- **Climate-Adaptive Operations and Maintenance**: Climate-adaptive operations and maintenance plans were suggested to be developed to address specific challenges posed by the local climate. This includes scheduled inspections, preventive maintenance, and rapid response protocols during extreme weather events.

These climate-resilient factors collectively contribute to the viability and sustainability of solar power plants in diverse environmental conditions. Implementing a combination of these measures was established to enhance the overall performance and longevity of solar power systems, making them more resilient to the challenges posed by climate variability.

4.3. Constraints for climate-adaptive solar plants

Collecting data for climate-adaptive PV (Photovoltaic) solar plants in Kajiado County, Kenya, was acknowledged to present various challenges due to the region's specific characteristics. Below were the results of the potential data collection constraints that were uncovered from the stakeholder interviews which are attributed to a study by Zhang *et al*. (2020), which delved into the data collection constraints for climate-adaptive solar plants. Sengupta and Barik (2021) identified the constraints for climate-adaptive solar plants in Turkey and the results yielded are similar to some of the findings in this study.

- **Limited Historical Climate Data**: Kajiado County was identified to have limited historical climate data, especially in terms of long-term solar radiation patterns, temperature variations, and extreme weather events. Incomplete or inaccurate data was suggested to hinder accurate climate modeling.

- **Sparse Weather Stations**: Insufficient weather monitoring infrastructure was realized in Kajiado County which pose challenges in obtaining real-time, localized data. Weather stations were found to be crucial for understanding microclimates, which significantly impact the performance of PV solar plants.

- **Inadequate Infrastructure for Remote Sensing**: It was mentioned that remote sensing technologies, including satellite imagery, have the capability to offer valuable insights into land cover, vegetation, and climate patterns. Nonetheless, concerns were raised about the potential limitation of high-resolution data availability due to inadequate infrastructure for remote sensing data retrieval.

- **Challenges in Accessibility**: It was noted that certain areas in Kajiado County might be remote or challenging to access. This could present logistical challenges when it comes to reaching potential sites for solar power plants for tasks such as data collection, maintenance, and infrastructure development.

- **Community Engagement Barriers**: It was emphasized that the engagement with local communities is vital for gaining insights into traditional climate knowledge and practices. Nevertheless, challenges such as differences in language, cultural sensitivities, or a lack of trust within the community were mentioned as potential hindrances to effective communication and collaboration.

- **Financial Constraints:** It was stated that constrained financial resources for data collection activities, encompassing the installation and maintenance of monitoring equipment, might impede comprehensive and continuous efforts in gathering data.

- **Political and Regulatory Challenges**: It was highlighted that factors such as political instability or intricate regulatory environments could impact the capacity to collect and share data. It was underscored as crucial to navigate regulatory frameworks and establish partnerships with local authorities.

- **Human Capacity Constraints**: It was pointed out that there may be a lack of sufficient expertise in climate science, solar technology, and data analysis in the region. It was emphasized that overcoming this constraint could be achieved by building local capacity and fostering collaboration with experts.

4.4. Analysis of Suitable Land for PV solar power plant Installation and the reclassification of raster maps

4.4.1 Solar Radiation Suitability

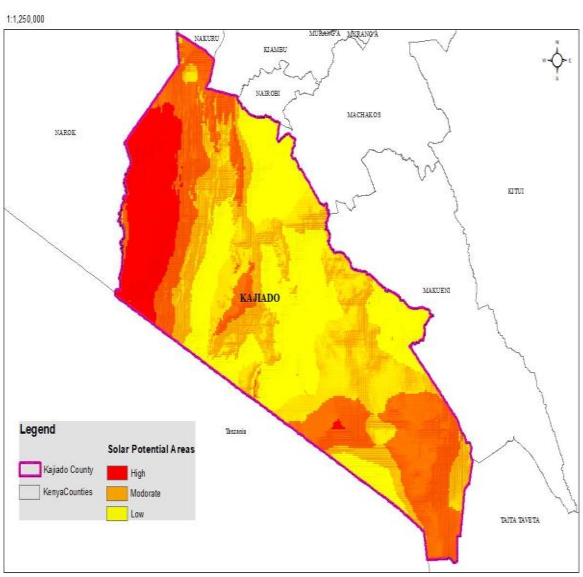
The solar radiation map of Kajiado County, depicted in Figure 6, provides valuable insights into the spatial distribution of solar energy potential across the region. The map was generated using a method that takes into account the solar irradiance values measured throughout the county, presenting a comprehensive overview of the solar potential variations. The observed solar irradiance for the area was notably high, registering at 2000 kWh/m^2 per annum.

Upon closer examination of the map, distinct patterns emerge, revealing varying levels of solar radiation across different parts of Kajiado County. Notably, the Western part of the county exhibits higher solar radiation values, highlighted in red, indicating an ideal environment for potential photovoltaic (PV) solar plant installation. Conversely, the Southern region displays moderate solar radiation values, depicted in yellow, suggesting a favorable but comparatively lower solar energy potential. In contrast, the Eastern part of the county is identified with lower solar radiation levels.

This spatial analysis aligns with findings from relevant literature, where studies have consistently emphasized the significance of geographical and climatic factors in determining solar radiation levels. Notably, a study by (Pravalie *et al.*, 2019) has previously underscored the importance of considering topographical features and regional climate patterns when assessing solar energy potential in a given area. The observed pattern in Kajiado County resonates with these established principles, reaffirming the influence of geographical orientation on solar radiation.

The identification of higher solar radiation levels in the Western part of Kajiado County supports the strategic placement of PV solar plants in this region, as it aligns with the broader understanding that areas with elevated solar potential contribute to enhanced energy generation. This localized knowledge, combined with insights from existing literature, forms a robust foundation for decision-making in the deployment of solar energy infrastructure in the region.

The solar radiation map was then reclassified into three classes. The reclassified solar irradiance map presented in Figure 12 displays the three classes of solar irradiance categorized based on their suitability for PV solar power plant installation in Kajiado County. According to findings outlined in the 2020 renewable energy law report for Kenya, regions experiencing solar irradiance of 3.56 kWh/m² per day were deemed economically viable. Consequently, areas where the solar irradiance was less than 3.56 kWh/m² per day were excluded from consideration in this study. The reclassification of raster solar irradiance was performed, designating areas as not suitable, (<5 kWh/m² per day), moderately suitable (5-6 kWh/m² per day), and suitable (>6 kWh/m² per day).



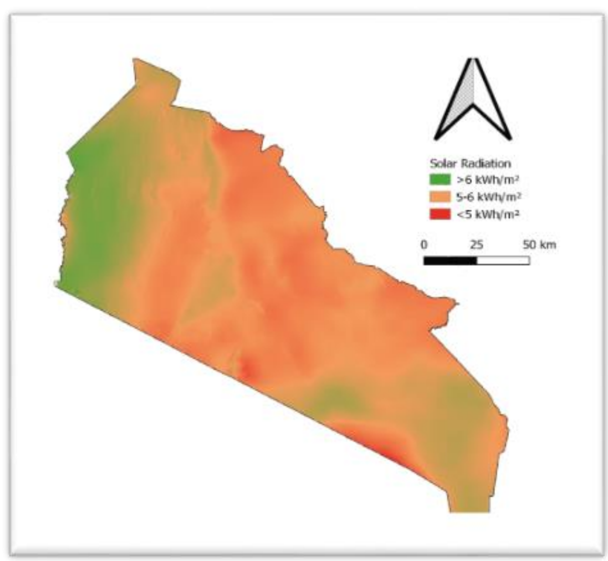


Figure 6: Solar Radiation Suitability map against the reclassified Solar Radiation map for Kajiado County

4.4.2 Soil Type Suitability

The soil type map, as depicted in Figure 7, offers critical insights into the soil characteristics relevant to the installation of photovoltaic (PV) solar power plants in Kajiado County. The analysis of soil types involved a comprehensive examination of various soil properties, including texture, organic matter content, and drainage characteristics. This investigation aimed to categorize the soil types present across different locations within the county.

The method employed for soil type analysis drew upon established techniques in soil science, incorporating field observations and remote sensing data. These methodologies collectively provided a detailed understanding of the soil profile and properties, guiding the categorization process. As presented in the soil type analysis, specific soil characteristics were identified as either favorable or unfavorable for PV solar plant installation. The areas with well-drained soils, characterized by good stability and low erosion potential, were deemed suitable for solar plant implementation. Eutric Regosols emerged as the most favorable soil type due to their more developed profile compared to other types. These soils exhibit moderate to high nutrient content and enhanced water-holding capacity.

A study by (Formolli *et al.*, 2022) emphasizes the importance of considering soil properties in solar energy project planning. The literature highlights the correlation between soil characteristics and the suitability of land for various purposes, including solar infrastructure development.

The findings of the soil type analysis revealed that the Western, Central, and Southern parts of Kajiado County possess soil characteristics conducive to PV solar plant installation. These regions, with well-drained soils and favorable stability, provide an optimal foundation for solar infrastructure. In contrast, the Eastern part of the county was identified as less favorable for solar plant installation due to specific soil properties that may pose challenges for stability and drainage.

This spatial analysis, integrating soil type considerations, further refines the site selection process for PV solar projects in Kajiado County, ensuring that areas with favorable soil characteristics are prioritized for optimal plant performance and long-term sustainability. The map was the reclassified into three classes according to their suitability for PV solar plant installation in Kajiado County. The consideration of soil composition played a pivotal role in determining the most favorable site for a solar photovoltaic (PV) power plant. In this context, Regosols emerged as the preferred soil type for providing adequate support for the installation of solar PV systems, while Cambisols were deemed unsuitable for such infrastructure support, as indicated by Gagnon *et al*. (2018). Reflecting the characteristics of the study area, the soil types were reclassified into three primary categories: Eutric Regosols were classified as suitable, Calcaric Fluvisols as moderately suitable, and Rhodic Cambisols as not suitable.

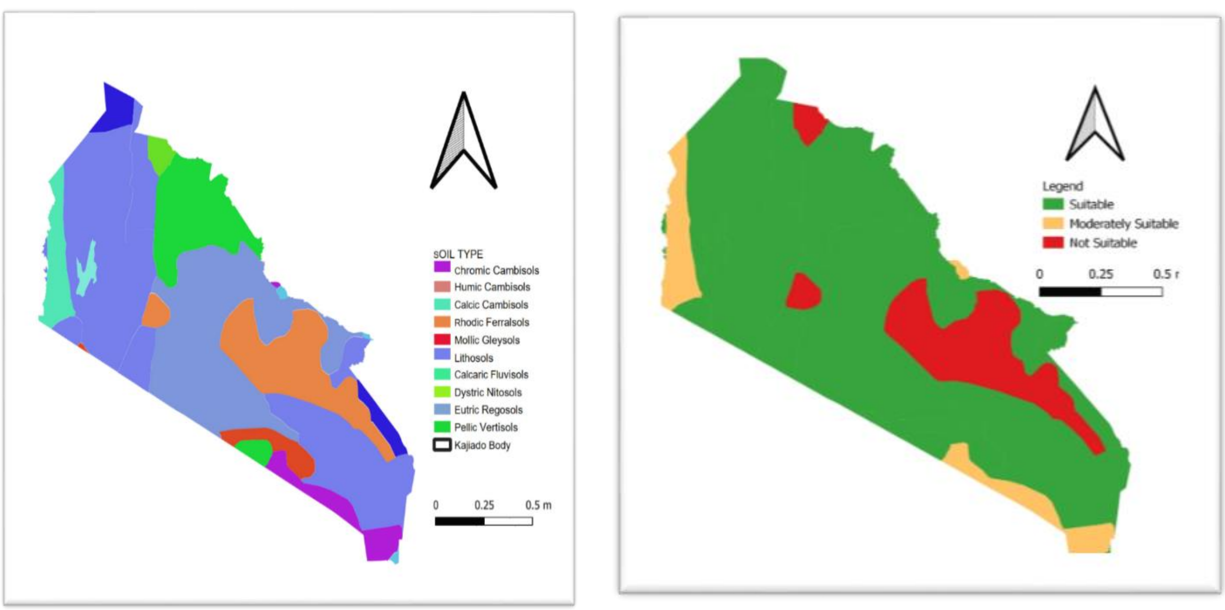


Figure 7: Type of soil Suitability map against the reclassified type of soil map for Kajiado County

4.4.3 Slope Suitability

The slope map, illustrated in Figure 8, serves as a critical tool in understanding the topography of Kajiado County and plays a pivotal role in assessing suitable locations for photovoltaic (PV) solar plant installation. This map was generated to categorize the study area into distinct slope classes, providing a comprehensive overview of the terrain's steepness.

The methodology employed for slope analysis encompassed mapping and analyzing the distribution of slopes throughout Kajiado County. By classifying the region into different slope categories, the analysis aimed to identify areas with varying degrees of steepness. The results derived from this analysis shed light on the terrain characteristics, ranging from gentle slopes to steeper inclines.

The slope map revealed that Kajiado County features diverse altitudes, with the lowest point situated at approximately 573 meters above sea level around Lake Magadi, and the highest altitude reaching 2554 meters above sea level around Ngong Hills. This variation in elevation is crucial for understanding the topographical profile of the area.

The significance of slope in assessing suitable locations for PV solar plant installation is evident in the findings presented in Figure 8 . Areas with gentle slopes are identified as favorable for solar plant installation due to several reasons. Firstly, gentle slopes simplify land preparation, making it more feasible for construction and installation activities. Secondly, they contribute to better stability for solar infrastructure.

Colak *et al.,* (2020), explains the importance of slope analysis in site selection for solar projects is emphasized. The literature underscores the need to consider topographical factors, such as slope, in optimizing the efficiency and longevity of solar infrastructure. The identification of suitable slope conditions aligns with best practices in solar project planning and contributes to the overall success and sustainability of solar energy initiatives.

The slope map and its accompanying analysis contribute valuable insights into the topographical characteristics of Kajiado County. This information is pivotal for identifying suitable locations for PV solar plant installation, ensuring that areas with gentle slopes are prioritized for optimal construction and long-term performance. The reclassified slope map illustrated in Figure 13 showcases three slope classes categorized according to their suitability for the installation of PV solar plants. The identification of appropriate sites for solar power plants was significantly influenced by the Earth's surface characteristics. The gradient of the Earth plays a crucial role in the reception of solar radiation. Consequently, flat terrains are more adept at capturing radiation, leading to increased energy generation from solar photovoltaic systems (Colak *et al.*, 2020). The elevation criterion involved categorizing areas into three suitability levels: those situated within gradient of <3% were reclassified as suitable, those between 3% to 7%gradient were deemed moderately suitable, and areas exceeding 7% gradient were considered not suitable. The analysis of slope reclassification datasets revealed that the Western part of the zone exhibited a flatter terrain. In contrast, the Northern part featured areas with steeper slopes.

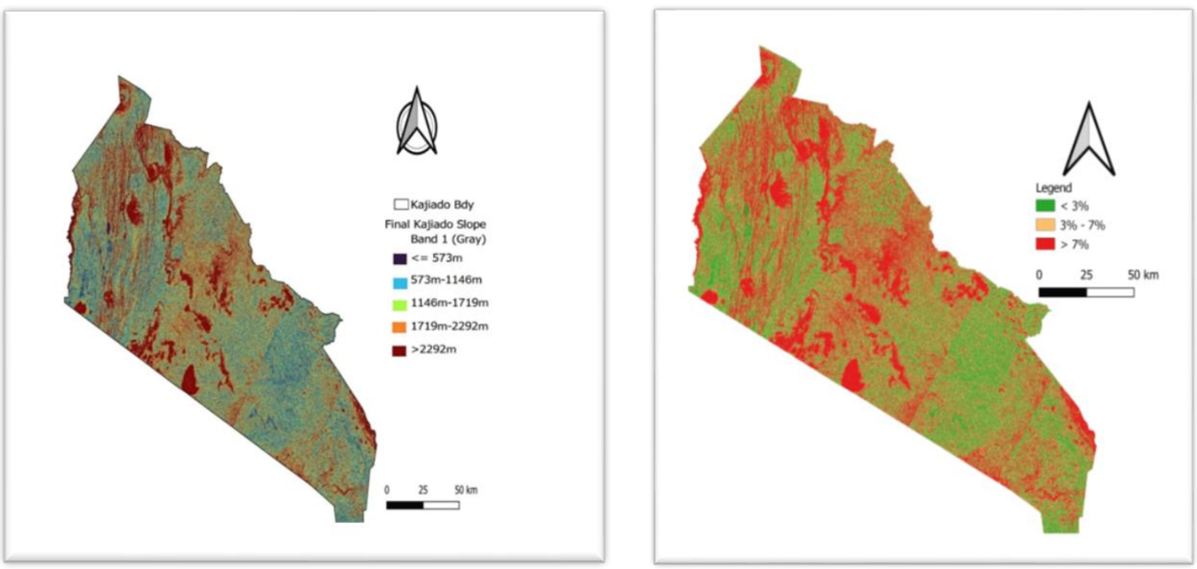


Figure 8: Suitability Slope map against reclassified slope map for Kajiado county

4.4.4 Land Cover Land Use Suitability

The Land Use Land Cover (LULC) map, depicted in Figure 9, plays a pivotal role in the strategic planning and site selection for the installation of photovoltaic (PV) solar plants in Kajiado County. This map was generated through a comprehensive land use land cover analysis, which involved classifying different land use types and mapping their distribution across the county.

The method used for the classification of LULC likely included remote sensing techniques, and satellite imagery to ensure accuracy in identifying various land use categories. This approach provided a detailed and accurate portrayal of the landscape, highlighting areas of vegetation, urbanization, built-up zones, water bodies, and bare land.

The significance of LULC in the context of installing PV solar plants include the following:

- **Identifying Suitable Land for Solar Installation:** The LULC analysis assists in pinpointing areas with suitable land use for PV solar plant installation. By categorizing land into different types, the study identified open land, particularly those with low-intensity land use like agricultural and barren areas, as suitable for solar infrastructure.

- **Assessing Compatibility with Existing Land Use:** The analysis goes beyond identifying open land and evaluates the compatibility of PV solar plant installation with existing land use types. Areas with minimal conflicts, such as those situated away from residential and protected zones, were deemed more suitable for solar plant development.

- **Optimizing Land Use Planning:** The LULC map aids in optimizing land use planning by aligning solar energy projects with land characteristics. It ensures that solar infrastructure is strategically placed to minimize environmental impact and conflicts with existing land uses.

The integration of LULC analysis in renewable energy planning is underscored by (Lin *et al.*, 2021). The study emphasizes the importance of understanding land use dynamics for sustainable energy development. It acknowledges that considering land use patterns enhances decision-making processes related to site selection, project design, and overall project success. LULC map and the associated land use land cover analysis provide critical information for identifying suitable locations for PV solar plant installation in Kajiado County. This approach ensures that solar projects are strategically placed in areas that align with land use characteristics, optimizing both energy generation and environmental sustainability.

The LULC map was then reclassified into three categories according to their suitability for PV solar power plant installation. As per Mancini and Nastasi (2020), the installation of PV solar plants avoids forested areas to prevent tree removal. In this research, Land Use and Land Cover (LULC) underwent reclassification into three primary categories: open areas were deemed suitable, grassland and open vegetation including water bodies were considered moderately suitable as the installation can be done on water bodies using buoyant structures like plastic pontoons to keep the afloat, finally, forests, urban areas, and protected zones were categorized as not suitable.

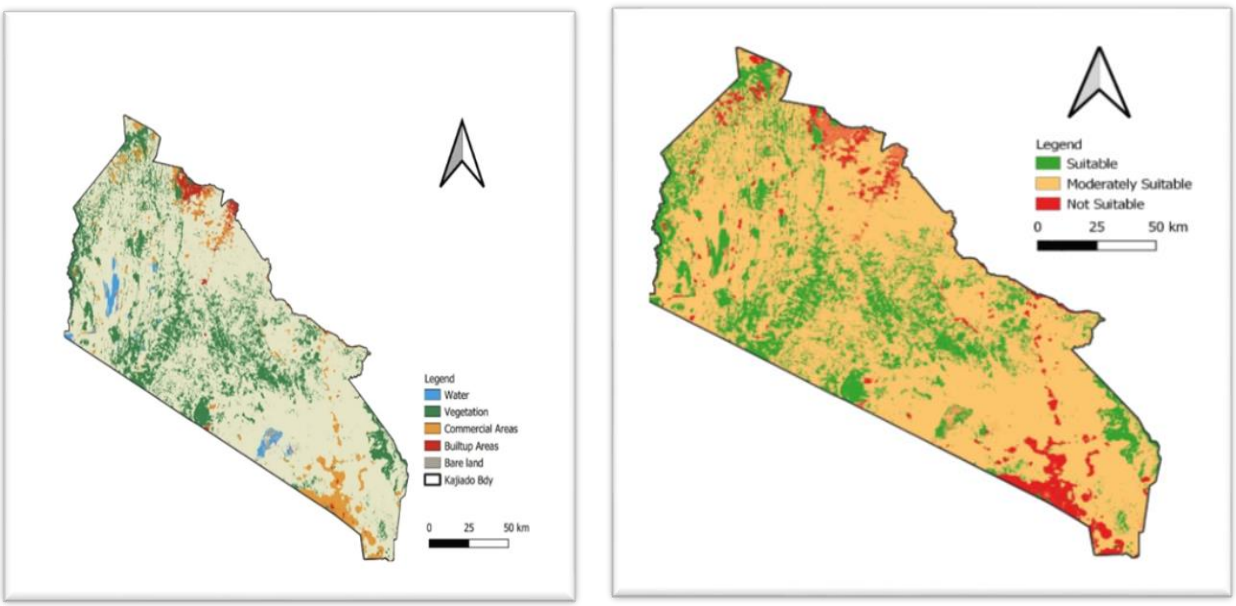


Figure 9: Land Use Land Cover Suitability map against the reclassified land use land cover map for Kajiado County

4.4.5 Distance from Roads Suitability

The Roads Network Analysis, illustrated in Figure 10, serves as a critical component in evaluating the existing road infrastructure within Kajiado County for the purpose of installing photovoltaic (PV) solar plants. This analysis involved mapping and assessing the road network to determine the accessibility of potential sites for solar plant installation.

The method used for road mapping likely incorporated Geographic Information System (GIS) technology, satellite data, and ground surveys to accurately capture the spatial distribution and characteristics of the road network in Kajiado County. The significance of distance from roads in the context of installing PV solar power plants is paramount. Key points include:

- **Assessing Transportation and Logistics:** The road network analysis helps assess the ease of transportation and logistics for the installation and maintenance of PV solar plants. Areas with good connectivity to existing roads are identified as more accessible, facilitating the transportation of equipment, personnel, and materials.

- **Determining Suitability for Solar Plant Development:** Accessibility is a critical factor in determining the suitability of an area for solar plant development. Areas with good road connectivity are considered more suitable for solar projects, as they enable efficient and cost-effective deployment and ongoing maintenance.

- **Minimizing Installation Challenges:** Proximity to well-connected roads minimizes challenges related to transporting heavy equipment and components to the installation site. It reduces costs associated with transportation and ensures timely and effective project implementation.

In comparing the results with a study by (Rahadian *et al.,* 2023), it is observed that similar findings emphasize the importance of road network analysis in site selection for renewable energy projects. These studies acknowledge that well-connected road infrastructure contributes significantly to the success and efficiency of solar plant installations.

Distance from roads was then reclassified into three categories as depicted in Figure 15. According to Nebey *et al*., (2020), the areas far from roads are not economically feasible and unsuitable. Therefore, locations with a distance of less than 500 m are selected as highly suitable sites for solar PV since proximity to roads provides easy access for transporting solar panels, equipment, and personnel to the installation site. This can significantly reduce logistical challenges and costs associated with transportation. In this study, distance from roads was reclassified into three categories, areas within a distance of 500m-1000m are considered suitable, 1000m-1500 m were considered moderately suitable, and greater than 1500 m not suitable

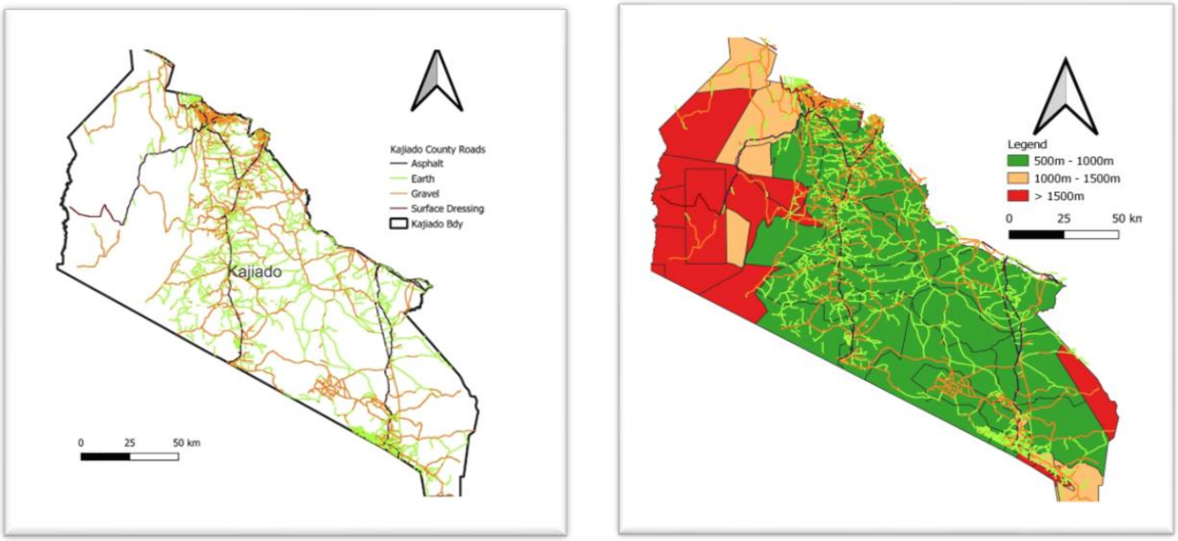


Figure 10: Map depicting the distance from roads in Kajiado County against the reclassified map for distance from roads

4.5. Locations of Schools and Health Centers

Figure 11 illustrates the consideration of schools and health centers' locations in the assessment of potential sites for solar power plants in Kajiado County. This analysis aimed to weigh the advantages and disadvantages of siting a solar power plant in proximity to these critical institutions.

The methodology involved evaluating how the presence of a solar power plant might impact the availability of resources, particularly electricity, for schools and health centers. Proximity to these facilities was a key factor in determining the potential benefits, such as enhanced access to clean and renewable energy, as well as drawbacks, including possible temporary disturbances during construction and operation.

Assessing the proximity of schools and health centers to potential solar power plant locations facilitated the evaluation of whether the plant's output could effectively contribute to meeting the energy needs of these critical institutions. A study by (Ioannidis *et al.*, 2022) emphasizes the importance of considering the proximity of critical institutions when planning renewable energy projects. The literature underscores the need for a comprehensive assessment of potential benefits and risks to ensure the sustainable and responsible development of solar power infrastructure.

By considering the proximity to schools and health centers, the study took a proactive approach in assessing potential risks and implementing measures to mitigate any adverse effects on the surrounding community. This approach aligns with best practices in renewable energy project planning, ensuring that the positive impacts of solar power generation are maximized while addressing and minimizing any potential negative consequences.

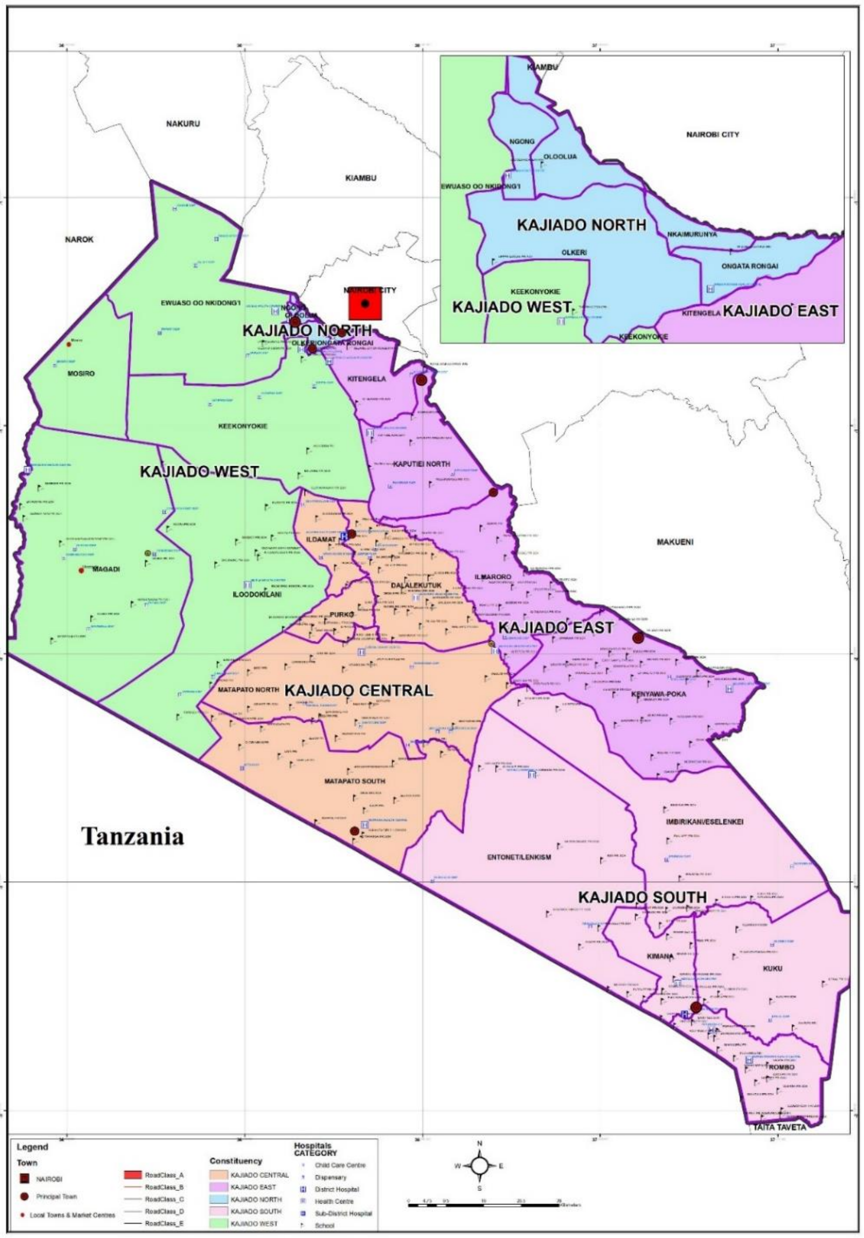


Figure 11: Schools and Health Centers in Kajiado county

4.6. Pairwise Comparison matrix

One effective method for evaluating and prioritizing different factors influencing solar radiation is the pairwise comparison matrix as presented on Table 5. The suitability metrics were evaluated and compared using the Saaty scale (table 2) to determine the relative influence of each metric. This process led to the creation of a pairwise comparison matrix. Pairwise comparisons were performed to determine the relative importance of criteria and sub-criteria. For each pair of criteria, their importance was assessed by experts and a numerical value was assigned to represent the relative priority. By utilizing this matrix, elements such as solar radiation, slope, land use and land cover (LULC), soil composition, and roads were systematically compared and assessed based on their relative importance in influencing solar radiation patterns. This approach enabled the researcher to make informed decisions regarding solar energy utilization, land management, and infrastructure development, ultimately contributing to sustainable and efficient resource utilization.

Table 5: Pairwise Comparison Matrix

	Solar Radiation	**Slope**	**LULC**	**Soil**	**Roads**
Solar Radiation	1	3	7	5	9
Slope	1/3	1	5	3	7
LULC	1/7	1/5	1	1/3	5
Soil	1/5	1/3	3	1	7
Roads	1/9	1/7	1/5	1/7	1

4.7. Criteria Weights Assignment

The respective weights of the criterion were determined by normalizing Table 5: Pairwise Comparison Matrix. The normalized values represented the significance of each criterion in comparison to others in relation to the main objective as shown on Table 6. It was observed that the technical factors have high influence compared to the economic and environmental factors since solar irradiance directly affects the energy output of solar panels and the slope of the land impacts the efficiency of solar energy capture. Solar irradiance had the highest weight of 49% while roads had the lowest weight of 3%.

Table 6: Normalized Pairwise Comparison Matrix

	Solar Radiation	**Slope**	**LULC**	**Soil**	**Roads**	**Weight**
Solar Radiation	0.56	0.64	0.43	0.53	0.31	0.49
Slope	0.19	0.21	0.31	0.32	0.24	0.25
LULC	0.08	0.00	0.06	0.03	0.17	0.07
Soil	0.11	0.07	0.19	0.11	0.24	0.14
Roads	0.06	0.03	0.01	0.01	0.03	0.03

4.8. Suitability Map for Solar PV Plant Installation

After considering all the criteria, a map was generated by overlaying the reclassified datasets to show suitable locations for the installation of photovoltaic solar power plants. The ultimate suitability map shown in Figure 12 was generated by multiplying each reclassified value by its corresponding weight and summing up all layer products (Guhen, 2021). The green color on the map represents the suitable locations mostly on the Western region and some parts of the Southern region, which account for 22% of the entire county. The amber color represents moderately suitable locations which covers some parts of Southern and Northern region, covering 31% of the study area. Lastly, the red color indicates not suitable locations, mostly covering the Central and Eastern parts, comprising 47% of the entire region. The suitable areas were found to have a very high solar radiation potential. They are characterized by fairly flat terrain with good road access. The soil type, mostly Eutric Regosols, is favorable, and the land is bare, without being too close to schools or health centers. These factors helped in identifying areas with optimal conditions for maximizing solar energy generation as shown on Figure 12. The western part and other regions in the southern part of Kajiado County were deemed suitable, while the central and eastern parts were found to be not suitable.

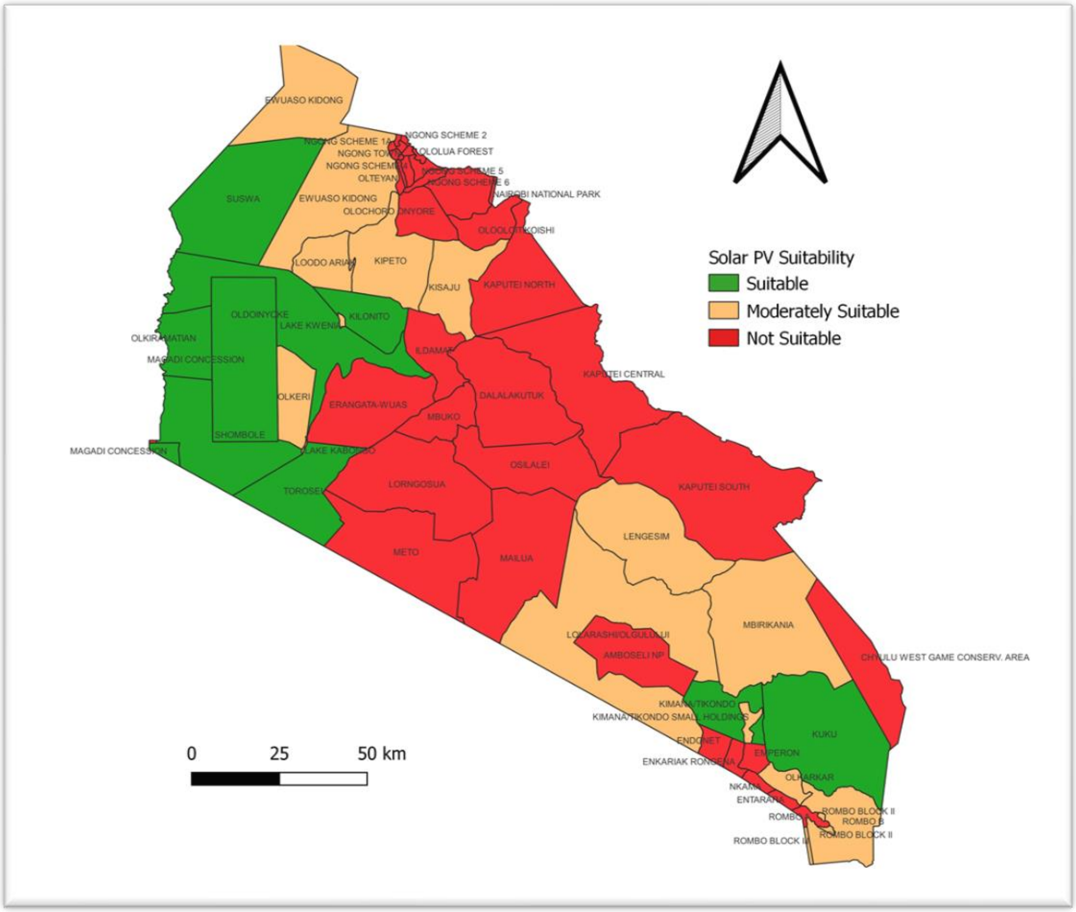


Figure 12 :Suitability Map for Solar PV Plant Installation

Areas with lower suitability exhibited less solar radiation potential. Some regions, such as those around Ngong' hills, had hilly slopes, making them not suitable. Additionally, regions around Amboseli National Park were considered not suitable due to their status as protected areas. Regions around Ongata Rongai and Loitoktok were also found to be not suitable as they are commercial and built-up areas.

Finally, certain areas were classified as moderately suitable, like the Olkeri region, which receives high solar radiation. These regions are next to water bodies like Lake Magadi, and their suitability falls under the moderate category because even though there is a water body, the region can be considered by installing floating solar power plants due to the high solar radiation potential that it receives.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Solar energy being one of the renewable energy sources is a readily available and cost-effective renewable resource that holds significant potential for widespread utilization. It offers numerous advantages, including low upfront investment and maintenance costs, making it economically feasible for exploitation. Additionally, solar energy proves particularly beneficial for electrifying remote regions lacking access to the national power grid, as it allows for the installation of off-grid systems to provide reliable electricity in these areas.

This study was aimed to assess suitable locations for photovoltaic solar power plants in Kajiado county using GIS. The study has successfully utilized GIS technology to analyze various factors and criteria for identifying suitable locations for PV solar plant installation. The study has provided valuable insights into climate-resilient factors, data collection constraints, and climate-informed GIS analysis. This research aimed to contribute to the development of sustainable and adaptive strategies for the deployment of solar power infrastructure in the region. Through the integration of spatial data, including solar radiation analysis, soil type analysis, slope analysis, roads analysis, and land use land cover analysis, a comprehensive assessment of potential areas for solar plant development has been achieved.

The results of this study showed 22% of the area of study to be more suitable, 47% being less suitable and 31% moderately suitable for PV solar plants installation of photovoltaic solar power plants. Identification of data collection constraints has highlighted the challenges associated with obtaining accurate and up-to-date information for climate-adaptive PV solar plants. The assessment indicated that considering various environmental parameters is crucial for the viability of solar power plants. The solar radiation analysis provided insights into the solar energy potential across Kajiado County, identifying areas with higher solar radiation intensity, which are more favorable for PV solar plant installation. The soil type analysis helped determine the suitability of different soil types, with a focus on Eutric Regosols being more favorable for solar plant installation due to their deeper profiles and better water retention capacity. The slope analysis contributed to identifying areas with gentle slopes, which are preferable for ease of construction and maintenance of solar plants. The roads analysis emphasized the importance of accessibility and transportation logistics for efficient installation and maintenance of solar plants. Lastly, the land use land cover analysis assessed the compatibility of solar plant installation with existing land uses, identifying low-intensity land use areas suitable for development. These economic, environmental and technical factors were then weighted together using Analytical Hierarchy Process.

5.2 Recommendations

This section highlights the recommendations based on the findings and conclusions of the research.

1. This study recommends investment in training programs and capacity building for local stakeholders involved in solar energy projects. This entails equipping professionals with the skills necessary to leverage GIS tools for ongoing monitoring, maintenance, and future expansion of solar installations.

2. The study recommends development and implementation of policies that support the growth of solar energy in Kajiado County. This includes incentives for renewable energy projects, streamlined permitting processes, and regulations that promote sustainable development.

3. The study recommends that public education should be conducted to create awareness on the renewable sources of energy mostly in remote areas. This should be considered to embrace sustainable development practices promoting the use of clean and environmentally friendly energy sources, reducing dependence on fossil fuels and mitigating the impacts of climate change.

4. This study further recommends that continual advancements in satellite technology should be considered to help enhance the availability and accuracy of Global Horizontal Irradiance data. Investments in satellite missions specifically designed for solar radiation monitoring,

improved sensor capabilities, and higher temporal and spatial resolutions can improve the coverage and quality of Global Horizontal Irradiance data, even in remote areas.

REFERENCES

Alternative Energy Tutorials 2021**.** *Solar Power*, (2021, May 7)**,** https://www.alternative-energy-tutorials.com/

Ahmad, J., Ali S, Muhammad S, Hussein, and Asif R. (2020). Evaluating Green Technology Strategies of the Sustainable Development of Solar Power Projects, (13). *Sustainability*, 123-150

Alhamad, A., Quian, S., and Tao, Y., (2022). Optimal Solar Plant Site Identification Using GIS and Remote Sensing: Framework and Case Study. *Energies*, 15(1), 312

Angel, A., and Bayod Rujula, (2009). Future development of the electricity systems with distributed generation. *Energy*, (34), 377-383

Arslan, O., and Turan, O., (2016). An application of fuzzy-AHP to ship operational energy efficiency Measures. *Ocean Engineering* (121), 392-402

Attia, S and Romain, L., (2020). Future trends and main concepts of adaptive facade systems. *Energy Science and Engineering*, 8(9)

Ayhan, H., Sinem and Jacob T. Competing Energy visions in Kenya. (2017 December) p. 196. *The Political Economy of Coal.*

Azmi Rida and Hicham Amar (2022). Decision analysis related to solar farm investments based on analysis hierarchical process and fuzzy AHP for sustainable energy production. *Energy Research* (46), 11730-11755

Beata S., and Joachim Vogt (2020). GIS-based approach for the evaluation of wind energy Potential. *Renewable and Sustainable Energy Reviews*, (15), 1696-1707

Benasla Morkhtar and Denis Hess (2019). The transition towards a sustainable energy system in Europe. *Energy Strategy Reviews*, (24), 1-13

Bishonge, O., Kombe, G., and Mvile B., (2020). Renewable energy for sustainable development in sub-Saharan African countries: Challenges and way forward. *Journal of Renewable and Sustainable Energy*, (12), 052702

Campell C., Ong, S. and Denholm P., (2017). Land-Use Requirements for Solar Power Plants in the United States. *Energy*, (13)

Campbell, S., Greenwood, M., and Walker, K. (2020). Purposive sampling: complex or simple? Research case examples. *Sage Journals*

Castillo, P., Carolina, S., and Carlo L., (2016). An assessment of the regional potential for solar power generation in EU-28. *Energy Policy*, (88), 86-99

Charles M. R., (2013). Renewable Energy Projects, financing risks in developing countries: Options for Kenya towards the realization of vision 2030. *International Journal of Business and Finance Management Research*, 1-10

Chisika, S., N., and Yeom, C., (2021). Enhancing Sustainable Development and Regional Integration through Electrification by Solar Power: The Case of Six East African States. *Sustainability*, 13(6), 3275

Cieck, A., Gos, A and Kamil, K., (2022). Accuracy analysis of aircraft positioning using real radar and GPS data. *Library of Science*,116

Colak H., Tugba Memisoglu and Yasin Gercek (2020). Optimal Site Selection for Solar Photovoltaic (PV) power plants using GIS and AHP. *Renewable Energy*, (149), 565-576

Damon, T., and Vasilis F., (2011). Environmental impacts from the installation and operation of large-Scale solar power plants. *Renewable and sustainable energy reviews*, (15), 3261-3270

Denis, D., (2016). Sustainable Thinking and Environmental Awareness through Design Education. *Procedia Environmental Science*, (34), 70-79

Doorga, S., R (2019). Multi-criteria GIS-based modelling technique for identifying Potential solar farm sites: A case study in Mauritius. *Renewable Energy*, (133), 1201-1219

Formolli, M., Croce, S., and Vettorato, D., (2022). Solar Energy in Urban Planning: Lesson Learned and Recommendations from Six Italian Case Studies. *Applied Sciences*, 12(6) 2950

Gagnon, P., R. Margolis, J. Melius, C. Phillips, and R. Elmore, (2018). Estimating rooftop solar technical potential across the US using a combination of GIS-based methods, LIDAR data, and statistical modeling. *Environmental Research Letters*, 2(13)

Gallego A., and Baldomero S., (2019). Analyzing territory for the sustainable development of solar photovoltaic power using GIS databases. *Springer Link*, 764

Gambino, V., Del, R., and Paolo, C., (2019). Methodology for the Energy Need Assessment to Effectively Design and Deploy Mini-Grids for Rural Electrification. *Energies* 12(3), 574

Garni, A., Hassan, Z., and Anjali A., (2017). Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia. *Applied Energy*, (206), 1225-1240

Ghadami, N., Gheibi, M., and Kian Zhara., (2021). Implementation of solar energy in smart cities using an integration of artificial neural network, photovoltaic system and classified Delphi methods. *Sustainable Cities and Society,* (74) 103149

Giovanni, D., and Sabino G., (2010). Using an innovative criteria weighting tool for stakeholders Involvement to rank MSW facility sites with the AHP. *Waste Management*, (30)

Guan, F., Young, Z., and Martha S., (2009). Evaluation Research on the Quality of the Railway passenger service based on the linguistic variables and the improved PROMETHEE II Method. *Journal of Computers*, 4(3)

Guhen, M., (2021). Determination of the suitable sites for constructing solar photovoltaic (PV) power plants in Kayseri, Turkey using GIS-based ranking and AHP methods. *Environmental Science and Pollution Research*, 28, 57232-57247

Gupta, A., and Sharma, P., (2022). Weather Impact on Solar Farm Performance: A Comparative Analysis of Machine Learning Techniques. *Sustainability*, 15(1), 439

Gorbunov, A., and V. B, (2019). Nature protection potential of wildlife sanctuary: Protection and Preservation of its Ecological Biodiversity. *Ekoloji*,28(107), 5033-5037

Kajiado County Profile (2019). https://www.kajiado.go.ke/

Karimi H., Amiri S. and Huang J. (2019). Integrating GIS and multi-criteria decision analysis for landfill site selection, case study: Javanrood County in Iran. *Springer Link*, (16),7305-7318

Kelvin, K., (2021). A feasibility study of sustainable offshore wind energy development in Kenya, *World Maritime University*.

Kircali, S and Selim, S, (2021). Site suitability analysis for solar farms using the geographic information system and multi-criteria decision analysis: the case of Antalya, Turkey. *Springer link*, (23), 1233-1250

Rahadian, H. and Bawono, A., (2023). Enabling Clean and Smart Mobility in Indonesian Road Infrastructure to Achieve Sustainable Transport. *Proceeding KRTJ*, (16)1

Renewable Energy Law and Regulation in Kenya (2020). https://cms.law/en/int/expert-guides/cms-expert-guide-to-renewable-energy/kenya

Ruiz H. S, Sunarso A, Ibrahim-Bathis K., Murti S. A and Budiarto I., (2020). GIS-AHP Multi-Criteria Decision Analysis for the optimal location of solar energy plants at Indonesia. *Energy Reports*, (6), 3249-3263

Hernandez, R., Madison, K., and Mitchell L. (2015). Solar Energy development impacts on land cover Change and protected areas. *Arizona State University*, 112(44), 13579-13584

Ioannidis, R., and Mamassis, N., (2022). Reversing visibility analysis: Towards an accelerated a priori assessment of landscape impacts of renewable energy projects. *Renewable and Sustainable Energy Reviews*, (161), 112389

Jayachandran, M., Ranjith Kumar Gatla and Prasada Rao, K., (2022). Challenges in achieving Sustainable Development Goal 7: *Affordable and clean energy in light of nascent technologies*, (53)

Jen, Y., Ying, C. and Sin, Y. (2022). Utilizing high fidelity 3D building model for analyzing the rooftop Solar PV potential in urban areas. Solar Energy. *Solar Energy*, (235), 187-199

Kahraman, C., and Kiran Zahid (2021). Extension of TOPSIS model to the decision-making under complex spherical fuzzy information. *Springer Link*, (19), 10771-10795

Kenya Power (2022). https://www.epra.go.ke/wp-content/uploads/2023/01/ABRIDGED-KPLC-TARIFF-2023.pdf

Kenya Soil and Terrain database (2022),http://www.landscapesportal.org/layers/geonode:kensoter

Kenya Roads Board (2022), https://krb.go.ke/

Klagge, B., and C., N, (2020). Financing large-scale renewable-energy projects in Kenya: investor types, International connections and financialization. *Geografiska Annaler*, (102), 61-83

Kiplagat J., K and Wangi T., X (2011). Lessons Learned – NREL Village Power Program Flowers, Larry US Department of Energy. *Renewable and Sustainable Energy Reviews*, (15), 2960-2973

Li, Y., Rongjie, H and Huang, G., (2022). Sustainable conjunctive water management model for alleviating water shortage. *Journal of Environmental Management*, (304), 114243

Li, N., Yang, J and Tang, X., (2021). Spatiotemporal scale-dependent effects of urban morphology on meteorology: A case study in Beijing using observations and simulations. *Building and Environment*,240

Limya, A and Leena, A., (2021). Geospatial Analysis of Solar Energy in Riyadh Using a GIS-AHP-Based Technique. *International Journal of Geo-Information*, 10(5), 291

Lin, S., Huang, X and Fu, X., (2021). Evaluating the sustainability of urban renewal projects based on a model of hybrid multiple-attribute decision-making. *Land Use Policy*, (108), 105570

Liu, J., Jian, L and Wang, W., (2021). The role of energy storage systems in resilience enhancement of health care centers with critical loads. *Journal of Energy Storage*,33

Longa, F., Dalla and Bob van der Zwaan (2017). Do Kenya's climate change mitigation ambitions necessitate large-scale renewable energy deployment and dedicated low-carbon energy policy? *Renewable Energy*, (113), 1559-1568

Ma G., and Liu, P., (2009) Evaluation Research on the Quality of the Railway passenger service based on the linguistic variables and the improved PROMETHEE II Method. *Journal of Computers*, (14)

Madjib, T., Mohsen, Z., and Deborah, D., (2016). An integrated intuitionistic fuzzy AHP and SWOT method for outsourcing reverse logistics. *Applied Soft Computing*. (40), 544-557

Mancini, F., and Nastasi., B., (2020). Solar Energy Data Analytics: PV Deployment and Land Use. *Energies*, 13(2), 417

Maraun, D, Wetterhall F and Chandler R.E (2010). Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. *Reviews of Geophysics*, 48(3)

Martinez-Hernandez, Sadhukhan, J and Dugmore, T., (2020). Perspectives on "Game Changer" Global Challenges for Sustainable 21st Century: Plant-Based Diet, Unavoidable Food Waste Biorefining, and Circular Economy. *Sustainability*, 12(5), 1976.

Narbel, A., Govinda R. Timilsina, and Patrick S., (2012). The price of solar energy: Comparing competitive auctions for utility-scale solar PV in developing countries. *Renewable and Sustainable Energy Reviews*, (16), 449-465

National Renewable Energy Laboratory. A National Laboratory of the US Department of Energy, Office of Energy Efficiency Renewable Energy http://www.nerl.gov/gis/

Nathan, T., and Noara, K., (2022). Determinants of rooftop solar PV adoption among urban households in Ghana. *Renewable Energy Focus*, (43). 317-328.

National Environment Management Authority (2022). https://www.nema.go.ke/

National Historical Geographic Information System Minnesota Population Center, University of Minnesota http://www.nhgis.org

Ndiritu., S. W., and Katungi, M., (2020). The effectiveness of feed-in-tariff policy in promoting power generation from renewable energy in Kenya. *Renewable Energy*, (161), 593-605

Ndukwe, E. Chiemelu, C., Anejionu and Raphael I., (2021). Assessing the potentials of largescale generation of solar energy in Eastern Nigeria with geospatial technologies. *Scientific African* (12)

Nebey, A. H., Tayo, Z. B., and Gera., (2020). Site Suitability Analysis of Solar PV Power Generation in South Gondar, Amhara Region. *Journal of Energy*

Nevat, I., Pignatta, G and Lea, A., (2021). A decision support tool for climate-informed and socioeconomic urban design. *Springer Link*, 23, 7627-7651

Nina, S., (2021). Just sustainabilities: lessons from the Lake Turkana Wind Power project in Kenya. *Local Environment*

Noorollahi, Y., Senani, A and Ahmad, F., (2022). A framework for GIS-based site selection and technical potential evaluation of PV solar farm using Fuzzy-Boolean logic and AHP multi-criteria decision-making approach. *Renewable Energy*, (186), 89-104

Noorollahi Younes, Ryuichi Itoi and Hikari Fujii (2008). GIS integration model for geothermal exploration and well siting. Geothermics, (37), 107-131

Nowak, M., Dziob, K and Ludwisiak, L., (2020). Mobile GIS applications for environmental field surveys: A state of the art. *Global Ecology and Conservation*,23

Obasi, J., Ngoo, L., and Murithi, C., (2015). Sustainable Design of a Renewable Hybrid Energy Systems. *Journal of Energy Storage*, (14), 103266

Olabi, A and Ali, M., (2022). Renewable energy and climate change. *Renewable and Sustainable Energy Reviews*, 158

Palme, M., Privitera, R and Rosa, D., (2020). The shading effects of Green Infrastructure in private residential areas: Building Performance Simulation to support urban planning. *Energy and Buildings*, (229), 110531

Pete, O., and Sorensen, (1999). GIS Tools for Renewable Energy Modelling Renewable Energy. *Renewable Energy*, (16), 1262-1267

Pravalie, R., Patriche, C., and Bandoc, G., (2019). Spatial assessment of solar energy potential at global scale. A geographical approach. *Journal of Cleaner Production*, (209), 692-721

Purohit, I., and Shekhar S., (2013). Evaluating the potential of concentrating solar power generation in Northwestern India. *Energy Policy*, (62), 157-175

Rahman, T., Akther, M., S, and Sarker, S., K, (2020). Criteria for Site Selection of Solar Parks in Bangladesh. A Delphi-AHP analysis. *Asian Energy Studies*

Rambo, C., M, (2013). Renewable energy project financing risks in developing countries: Options for Kenya towards the realization of vision 2030. *International journal of Business and Finance Managing Research*, (110), 10

Renne, D. S., (2016). Resource assessment and site selection for solar heating and cooling systems, *Advances in Solar Heating and Cooling*, (30), 13-41

Rios, R., and Duarte, S., (2021). Renewable Energy in Kenya. *Renewable and Sustainable Energy Review*, 149

Saaty, R., W (1987). The Analytic Hierarchy Process –What it is and how it is used. *Mathematical Modelling*, (9), 161-176

Sengupta, A and Barik, A., (2021). Scope, Challenges, Opportunities and Future Goal Assessment of Floating Solar Park. *IEEE Xplore*

Seyfi, S., (2022). Techno-economic evaluation of a grid-connected PV-regeneration hydrogen Production hybrid system on a university campus. *International journal of Hydrogen Energy*

Suh, J., and Jeffrey R., (2016). Solar Farm Suitability Using Geographic Information System Fuzzy sets and Analytic Hierarchy Process. *Energies*, 9(8), 648

Sharma, M., K, Obinna N., and Bernard, M., P (2017). Challenges in Locating Solar Photovoltaic Power Plants. *Renewable and Sustainable Energy*, (64), 1054-1088

Silva, K., Janta, P., and Chollacoop, N., (2022). Points of Consideration on Climate Adaptation of Solar Power Plants in Thailand: How Climate Change Affects Site Selection, Construction and Operation. *Energies*, 15(1), 171

Takase, M., Kipkoech, R, and Kwame P., (2021). A comprehensive review of energy scenario and sustainable energy in Kenya. *Fuel Communications*, (7), 100015

Thad, G., and Joshua S., Fu, (2019). Air Quality, Third Edition. *Engineering and Technology*

Tiwari, A., Meir, I and Karnieli A., (2020). Object-Based Image Procedures for Assessing the Solar Energy Photovoltaic Potential of Heterogeneous Rooftops Using Airborne LiDAR and Orthophoto. *Remote Sensing*, 12(2), 223

United States Geological Survey Earth Explorer portal (2022), https://www.usgs.gov/

Vaidya, S., and Sushil, K., (2006). Analytic Hierarchy Process: An overview of applications, *European Journal of Operational Research*, (169), 1-29

Wang, F., and Zhang, X., (2022). A satellite image data based ultra-short-term solar PV power forecasting method considering cloud information from neighboring plant. *Energy*, (238)

Wang, J., You-Yin Jing, and Jun-Hong Zhao, (2009). Review on Multi-Criteria Decision Analysis aid in sustainable energy decision making. *Renewable and Sustainable Energy Reviews*, (13) 2263-2279

World Bank (2022), https://data.worldbank.org/

Wong, M., Rui, Z., and Lin Liu, (2016). Estimation of Hong Kong's solar energy potential using GIS and remote sensing technologies. *Renewable Energy*, (99) 325-335

Yan Li and Liu, C., (2017). Estimating solar energy potentials on pitched roofs. *Energy and Buildings*, (139), 101-107

Zhang Jianyuan, Li Zao and Ying Zhang (2017). A critical review of the models used to estimate solar radiation, *Renewable and Sustainable Energy Review*, (70), 314-329

Zhang, X., Wang Fu and Wang, W., (2020). The development and application of satellite remote sensing for atmospheric compositions in China. *Atmospheric Research*, 245

APPENDICES

Appendix 1: Research Questionnaire: Assessing Climate-Resilient Factors for Solar Power Plant Viability

Section 1: General Information

Name (Optional)____

Occupation/Expertise____

Years of Experience in Renewable Energy______________________________________

Section 2: Perception of Climate-Resilient Factors

a) Does your organization consider climate resilience planning when installing PV solar power plants?

Yes ☐ No ☐

b) How does your organization approach climate resilience planning in the context of solar power plant installations? ____

____

c) What specific climate factors do you consider when planning for the establishment of photovoltaic solar power infrastructure? ____________________________________

____

d) In your experience, how critical is the use of durable materials and coatings in solar panels for withstanding extreme weather conditions? Can you provide examples or instances where this design feature proved beneficial? ________________________

____

____

e) How effective do you find solar tracking systems in adapting to changing weather conditions? Can you share any specific cases where dual-axis or smart tracking systems optimized energy capture? ____

____

f) From your perspective, how important are effective cooling mechanisms in mitigating the impact of high temperatures on solar panel efficiency? Can you share examples of successful integration of passive or active cooling systems? ________________________

____

g) In your experience, how crucial are weather-resistant inverters for the overall efficiency of solar power systems? Can you provide examples where these inverters demonstrated resilience in various temperature ranges? ____

____

h) From your knowledge, how does designing solar power systems with adaptive grid integration features contribute to addressing fluctuations in energy production and demand? Can you share experiences with smart grid technologies and energy storage solutions?

____
____
____

i) In your view, how important are sturdy and resilient mounting structures for anchoring solar panels securely, especially in areas prone to strong winds, heavy rainfall, or seismic activity? Can you provide examples of successful implementation?

____

____

Section 3: Additional Insights

Please provide any additional insights or recommendations related to climate-resilient factors in solar power plants that you believe are crucial but may not have been covered in the previous questions.____
____
____
____

Appendix 2: Research Questionnaire: Identifying Data Collection Constraints for Climate-Adaptive PV Solar Plants

Data Collection Infrastructure

1) What types of data are crucial for implementing climate-adaptive features in PV solar plants? ____

____

2) Can you describe the current infrastructure and systems in place for collecting climate-related data for solar energy projects? ____

____

Data Availability

1) Have you encountered any challenges in terms of availability of climate data relevant to solar power plant installation?

   Yes ☐ No ☐

2) What challenges do you encounter in terms of the availability of climate data relevant to solar power plant installations? ____

____

3) Are there specific climate parameters for which data availability is particularly limited or unreliable? ____

____

4) Are there instances where the granularity of climate data has posed challenges in decision-making? ____

____

5) Are there technological constraints or limitations that affect the collection of climate data for climate-adaptive solar projects?

   Yes ☐ No ☐

6) List the data collection constraints for climate adaptive PV solar plants.