Master’s Thesis of International Studies

Assessing Geothermal Energy Technologies for Kenya's Energy Sector Transformation:

Leveraging on carbon credits, environmental protection, and social acceptance

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By

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Abstract

Assessing Geothermal Energy Technologies for Kenya's Energy Sector Transformation:

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This paper explores the potential impact of carbon trading on the development of geothermal energy technology in Kenya, examining its implications for environmental conservation and social acceptance of geothermal projects. Geothermal energy, a renewable resource derived from the Earth's internal heat, plays a crucial role in Kenya's Least Cost Power Development Plan (LCPDP) 2024-2043. With geothermal energy projected to constitute 36% of the total effective capacity by 2043, there is a pressing need for sustainable practices to optimize its utilization. Concurrently, carbon trading mechanisms provide economic incentives for reducing greenhouse gas emissions, aligning with global efforts to mitigate climate change. Kenya's updated Climate Change Act and the Carbon Credit Trading and Benefit Sharing Bill underscore the importance of a transparent and accountable carbon market, which could enhance the financial viability of geothermal projects while promoting social equity through community benefit-sharing agreements. The research aims to assess how carbon trading can encourage investment in geothermal energy, provide additional revenue streams, and foster environmental sustainability. Methodologies include a comprehensive review of Kenya's energy mix, legal frameworks, and case studies from the EU and China, which have successfully implemented emissions trading systems. PESTEL analysis will be used to evaluate and understand the external macro environmental factors that might influence the geothermal energy technologies. It will help to identify and assess the key factors in the Political, Economic, Social, Technological, Environmental, and Legal domains that can impact the success or failure of the two technologies under consideration. The findings will offer policy recommendations to optimize the synergy between carbon trading and geothermal energy development, ultimately supporting Kenya's goals of economic growth, energy security, and environmental sustainability.

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List of Abbreviations

EGS:	Enhanced Geothermal Systems
GDC:	Geothermal Development Company
GET:	Geothermal Energy Technologies
IEA:	International Energy Agency
IRENA:	International Renewable Energy Agency
KenGen:	Kenya Electric Generating Company
KPLC:	Kenya Power
LCPDP:	Least Cost Power Development Plan
MOE:	Ministry of Energy
MW:	Megawatts
RMB:	Chinese currency Renminbi
SDG:	Strategic Development Goal

Chapter I. Introduction

1.1 Background

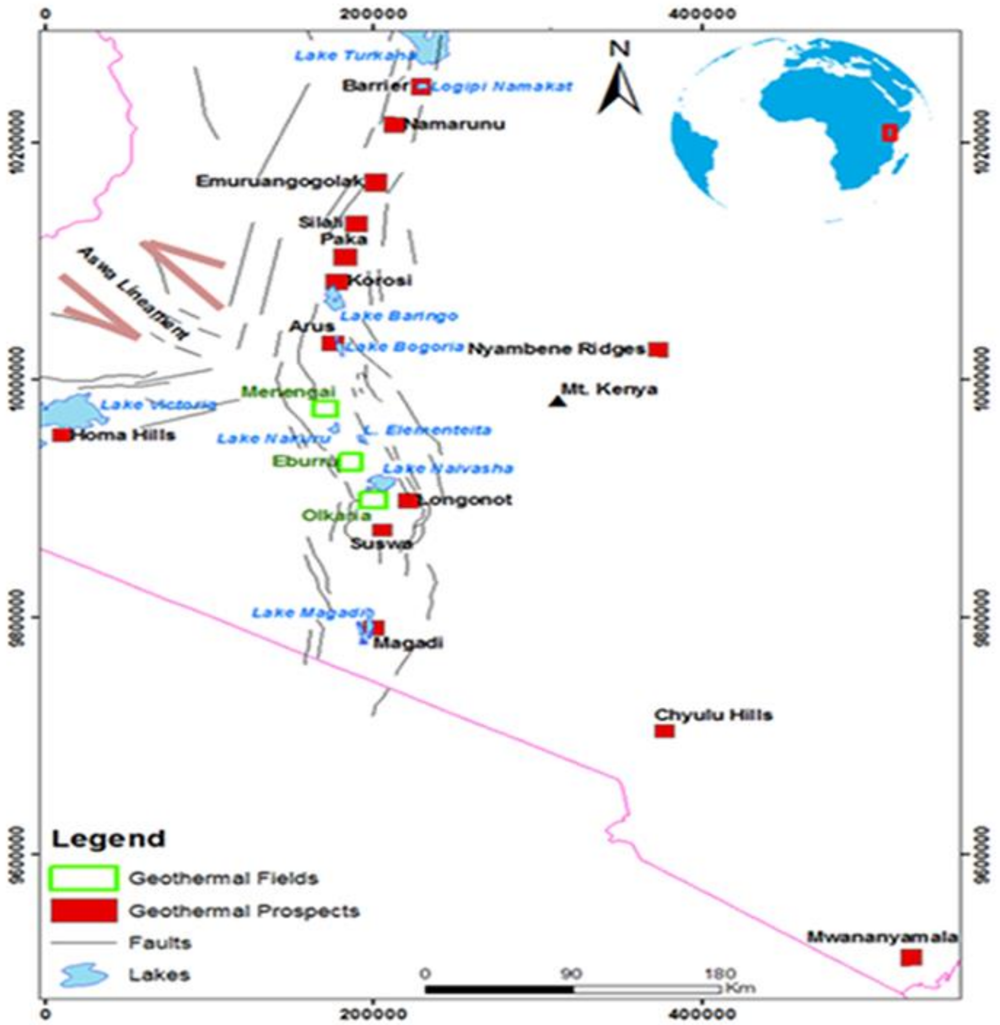
Geothermal energy is a type of renewable energy derived from the heat stored beneath the Earth's surface. This heat originates from the radioactive decay of minerals deep within the Earth, as well as from the heat absorbed from the sun at the Earth's surface. Geothermal energy is harnessed by tapping into naturally occurring hot water reservoirs or by drilling deep into the Earth's crust to access high temperatures.

In line with the Kenyan government's Least Cost Power Development Plan (LCPDP) spanning from 2024 to 2043, the effective capacity as of 2024 stands at 3,127 MW, projected to grow to 11,346 MW by 2043. Table 1.1 illustrates the installed capacity as well as the effective capacity of electricity in Kenya as of the year 2023 according to the ministry of energy (MOE).

Table 1.1: Installed and Effective Capacity as of 2024
Source: Kenya Power

	Installed	**Effective*/Contracted**	% (effective)	% (Installed)
Hydro	839.3	810.4	25.9%	25.9%
Geothermal	940.0	876.1	28.0%	29.0%
Thermal (MSD)	512.8	506.4	16.2%	15.8%
Thermal (GT)	60.0	56.0	1.8%	1.8%
Wind	435.5	425.5	13.6%	13.4%
Biomass	2.0	2.0	0.1%	0.1%
Solar	210.3	210.3	6.7%	6.5%
Import	200	200	6.4%	6.2%
Interconnected System	**3,200**	**3,087**	**98.7%**	**98.6%**
Off grid thermal	42.22	37.28	1.2%	1.3%
Off-grid Solar	3.39	3.21	0.1%	0.1%
Off-grid Wind	0.55	0.00	0.0%	0.0%
Total Off-grid	46.16	40.50	1.3%	1.4%
Total Capacity MW	**3,246**	**3,127**	**100.0%**	**100.0%**

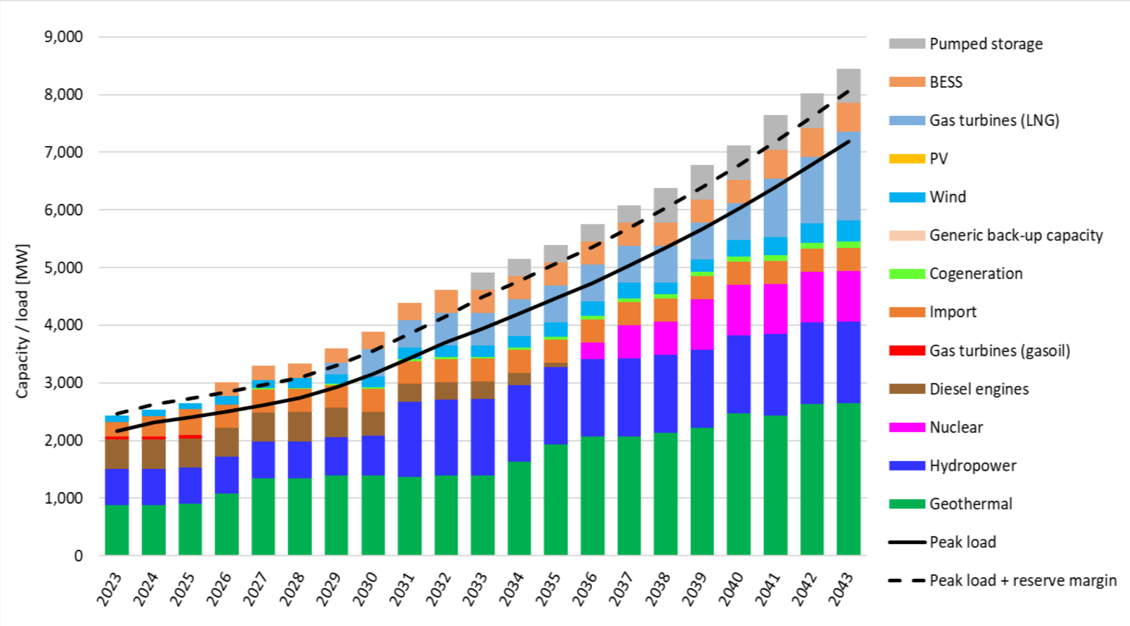
Geothermal energy is anticipated to be the primary contributor, constituting 36% by 2043 of the total effective capacity. Kenya is a leader in geothermal energy development in Africa, benefiting from significant resources located along the East African Rift System. The country's geothermal potential is estimated at approximately 10,000 MW, with most of this capacity concentrated in the Rift Valley region. Several high-temperature geothermal fields in this area present a valuable opportunity for sustainable energy production. The Olkaria geothermal field, located in Nakuru County, is Kenya's most developed geothermal resource. It currently supports multiple power plants with a combined capacity exceeding 900 MW, making it the backbone of the country's geothermal energy sector. Other prominent fields, such as Menengai, Suswa, Longonot, and the Baringo-Silali blocks, are at various stages of development. For instance, the Menengai field, with an estimated potential of 1,600 MW, is undergoing significant expansion to contribute more capacity to the national grid. The figure below illustrates the location of the geothermal potential areas in Kenya.



Source: KenGen

This therefore calls for the adoption of best practices to ensure sustainability and efficient utilization of the geothermal resources. Figure 1.1 shows the energy mix prediction as per the LCPDP 2023 to 2043 in relation to the capacity and the peak load demand scenario.

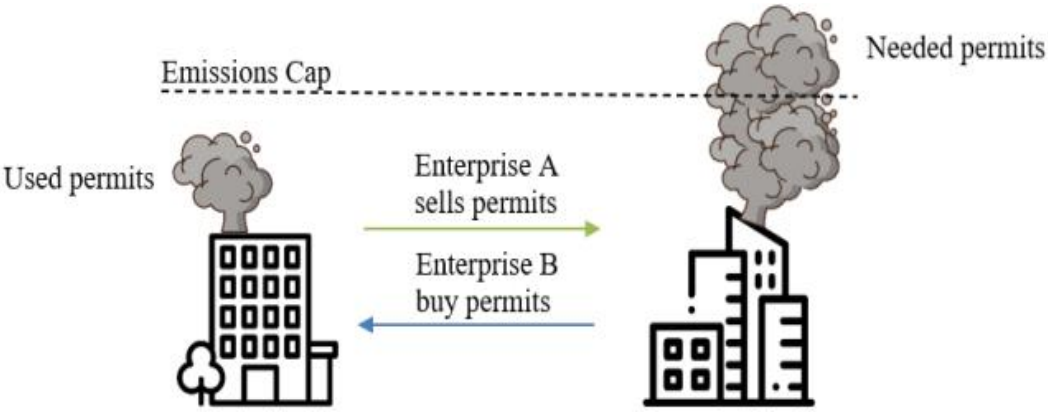
Figure 3: energy mix prediction



Source: LCPDP report 2023-2024.

Carbon trading, also known as emissions trading, is a market-based mechanism designed to reduce greenhouse gas emissions by providing economic incentives for achieving emissions reductions. It involves the buying and selling of carbon credits, which represent a permit to emit one ton of carbon dioxide or its equivalent. Countries or companies with lower emissions can sell their excess allowances to those struggling to meet their emission targets, thereby promoting cost-effective emissions reduction. The system can operate under regulatory frameworks like cap-and-trade programs or voluntary markets, encouraging an overall reduction in greenhouse gases and supporting the transition to a low-carbon economy (Hepburn, 2007). Figure 1.2 shows how a carbon trade transaction happens between two entities.

***Figure 1.4*: Carbon trading scheme between two players**



Source: Indonesia Carbon Trading Handbook, 2022.

According to the carbon credit portfolio, report by Kengen, Kenya registered six projects under the Clean Development Mechanism (CDM). This aims to support mitigation of climate change according to the Kyoto Protocol. The six projects have a potential of reducing 1.5 million CO_2e annually, and this was issued 5,057,253 Certified Emission Reduction (CER), of which approximately 1 million were commercialized (KenGen carbon credit portfolio report of 2020). KenGen utilized 10% of the income to help support projects of host communities as listed in Table 1.0.2

Table 1.2: Community Benefit Programs

<table>
<tr><th>Community Benefit Project</th><th>Associated CDM Project</th></tr>
<tr><td>Construction of Ngurunga Earth Dam</td><td>Kiambere Hydro Project</td></tr>
<tr><td>Rehabilitation of Mirira Primary School and associated infrastructure</td><td rowspan="3">Tana Hydro Project</td></tr>
<tr><td>Rehabilitation and equipping of Kiambaa Primary School</td></tr>
<tr><td>Construction of the Mirira Dam footpath</td></tr>
<tr><td>Construction and equipping of three classrooms in Oloiruwa Primary School</td><td rowspan="3">Olkaria II Geothermal Project</td></tr>
<tr><td>Excavation of Oloosing’ate water pan</td></tr>
<tr><td>Construction and equipping of three classrooms in Nkaampani Primary</td></tr>
</table>

Construction and extension of a 10-kilometer Maiella waterline	

To support and regulate its carbon market, Kenya has developed comprehensive legislation and frameworks in line with Article 6 of the Paris Agreement. The 2023 amendment to the Climate Change Act introduced enhanced regulatory measures, including the establishment of a national carbon registry and the requirement for mandatory environmental and social impact assessments for carbon trading projects. These changes aim to ensure that carbon-trading activities will be conducted transparently and responsibly, fostering an accountable carbon market within the country (Nkatha, 2023). Geothermal plants, being green energy projects, can leverage this low-hanging fruit to increase revenues, making geothermal power plants more economically viable and attractive to investors.

Furthermore, the Carbon Credit Trading and Benefit Sharing Bill is designed to establish a clear regulatory framework for carbon credit trading while ensuring equitable benefit-sharing among stakeholders (Carbon Trading Bill, National Assembly Bill of 2023). A key provision of the bill is the requirement for community development agreements, which mandate that local communities receive at least 25% of the aggregate earnings from carbon projects. This provision ensures that the economic benefits of carbon trading are shared with those most impacted by the projects, promoting social equity and community development alongside environmental sustainability. This will increase the level of acceptance of geothermal power plant projects in the community, reducing the project implementation risk and, as a result, reducing the initial investment cost.

1.2 Research Question

How will carbon trading impact geothermal energy technology development in Kenya, promoting environmental conservation as well as promoting social acceptance of geothermal projects in the country?

1.3 Purpose

The purpose of this research is to assess how carbon credits can be leveraged to enhance the financial viability and promote advancement in geothermal energy projects in Kenya. This involves evaluating the impact of carbon trading mechanisms on providing additional revenue streams through the sale of carbon credits, attracting investment into geothermal energy generation, promoting environmental sustainability, and enhancing social acceptance of geothermal energy projects.

1.4 Thesis Structure

Chapter one provides the background of the research by offering an overview of geothermal energy as a renewable resource, highlighting its significance within Kenya's current energy landscape. It also discusses the role of geothermal energy in the country's Least Cost Power Development Plan (LCPDP) for the period 2024-2043. The introduction to carbon trading and its relevance to renewable energy is also covered. The research question in the chapter focuses on how carbon trading will impact the development of geothermal energy technology in Kenya, particularly in promoting environmental conservation and enhancing social acceptance of geothermal projects. The chapter highlights the purpose of the study, which is to examine the impact of carbon credits on the financial viability of geothermal projects in Kenya and to explore how carbon trading can further environmental sustainability and social acceptance of these projects.

Chapter 2 presents a literature review beginning with the history of geothermal energy development, offering a global historical context and tracing the evolution of geothermal technologies from ancient applications to modern power generation. It provides an overview of various geothermal power plant technologies, including dry steam, flash steam, and binary cycle, and discusses the advantages and challenges associated with each. The chapter also explores the environmental impact of geothermal energy by comparing its emissions to those of fossil fuel plants, highlighting geothermal energy's role in reducing greenhouse gases and supporting global climate goals. Additionally, it explains carbon trading mechanisms and their significance in reducing emissions, emphasizing how carbon trading promotes renewable energy development, including geothermal energy. The chapter concludes with global case studies, focusing on the European Union Emissions Trading System (ETS) and China's ETS.

Chapter 3 outlines the methodology, starting with an analysis of Kenya's current and projected energy mix as detailed in the Least Cost Power Development Plan (LCPDP) 2024-2043. It then evaluates the legal framework for carbon trading in Kenya, with a focus on the Climate Change Act and related regulations. The chapter includes a comparative analysis of carbon trading systems in the European Union and China, followed by a PESTEL analysis to assess external factors influencing geothermal energy development in the context of carbon trading.

Chapter 4 presents the results, beginning with an overview of the current state of geothermal energy in Kenya, including a review of installed and effective capacity as of 2024 and projections for its utilization by 2043. It then compares carbon emissions from different geothermal technologies, specifically flash steam and binary cycles. The chapter also analyzes Kenya's legal framework for carbon credits and its implications for geothermal energy projects. Additionally, it provides a case study analysis of the European Union and China’s carbon trading mechanisms, evaluating their relevance and applicability to the Kenyan context.

Chapter 5 discusses the impact of carbon trading on geothermal energy development in Kenya, focusing on how it can improve the financial viability of these projects. It also explores potential challenges and opportunities within Kenya's carbon trading framework that could influence geothermal energy development. The chapter further examines the role of carbon trading in enhancing social acceptance of geothermal projects and considers the environmental benefits and challenges associated with expanding geothermal energy in the country.

Finally, chapter 6 concludes the study by summarizing the key findings from the analysis of carbon trading's impact on geothermal energy in Kenya. It provides policy recommendations aimed at optimizing the integration of carbon trading with geothermal energy development. Additionally, the chapter outlines suggestions for future research, highlighting areas where further exploration is needed at the intersection of carbon trading and renewable energy in Kenya.

Chapter 2. Literature Review

2.1 History of Geothermal Energy Development

The historical development of geothermal energy can be traced back to ancient utilization in bathing, cooking, and heating. Natural hot springs, believed to have healing properties, played a significant role in the cultural and social activities. By the 19th century, geothermal energy began to be utilized for industrial purposes, with notable advancements in Larderello, Italy, where geothermal steam was used to extract boric acid from volcanic rock. Geothermal technology improved in the early 20th century, with the first successful attempt to generate electricity using geothermal energy by Prince Piero Ginori Conti in 1904, leading to the establishment of the first commercial geothermal power plant in Larderello by 1913 (DiPippo, 2015).

As the technology advanced with time, geothermal heat pumps emerged in the 1940s, utilizing stable underground temperatures for heating and cooling buildings, a technology that has since become widespread. Concurrently, in the year 1960 in Geysers, California, a first large scale geothermal power plant was built. In the late 20th and early 21st centuries, geothermal energy experienced significant technological advancements and global expansion.

Countries like Iceland became global leaders in utilizing geothermal energy for both power generation and direct heating applications. Recent trends have focused on increasing the capacity and efficiency of geothermal power plants, integrating geothermal energy with other renewable sources, and expanding direct use applications. These developments, coupled with supportive policies and international cooperation with institutions such as IRENA, have supported the adoption of geothermal energy as a sustainable and viable component of the global energy mix.

Geothermal energy extraction technologies utilize hydrothermal systems, including dry steam, flash steam, and binary cycle power plants. Dry steam plants are the oldest type that directly use geothermal steam to drive turbines and generate electricity. Flash steam plants that are the common technology currently operate by depressurizing high-temperature geothermal fluids to produce steam. Binary cycle power plants, the most recent technology in the geothermal energy market, use moderate-temperature geothermal fluids to heat a secondary fluid with lower boiling points, which then vaporizes to drive turbines. These hydrothermal systems are known for their efficiency and reliability, with binary cycle plants particularly noted for their ability to harness lower temperature resources, thus expanding the geographical reach of geothermal energy (Assad et al., 2017).

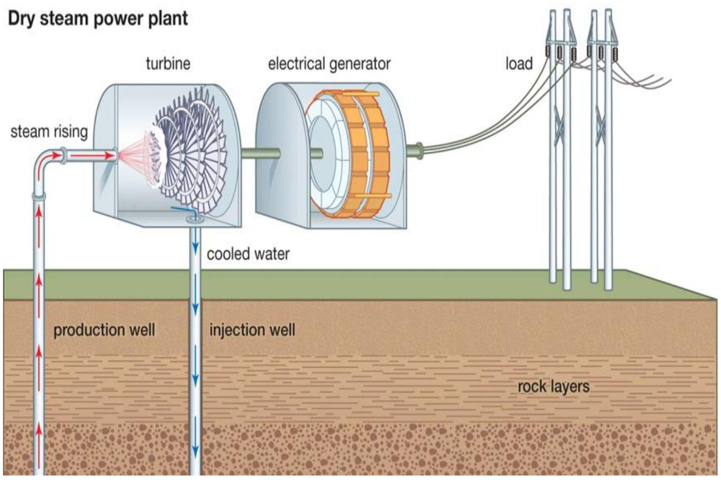
2.3 Transition of Geothermal Energy Technologies

The transition of geothermal energy technologies involves the evolution and adoption of advanced methods to harness the Earth's heat for sustainable energy production, improving efficiency, scalability, and environmental impact. Initially, geothermal energy exploitation began with simple technologies such as direct use applications and early power plants, primarily using dry steam and flash steam methods. The development of Enhanced Geothermal Systems (EGS) marked a significant improvement of geothermal technology, allowing energy production in areas without natural hydrothermal resources by creating artificial reservoirs (Lu, 2018). Additionally, the introduction of binary cycle power plants further expanded geothermal potential by utilizing lower temperature resources (Franco & Villani, 2009).

2.2.1 Dry steam geothermal power plants

Dry steam power plants utilize natural steam that comes directly from the geothermal reservoir to turn turbines, generating electricity. Figure 2.1 shows how a dry steam geothermal power plant works.

Figure 2.1 Dry steam power plant

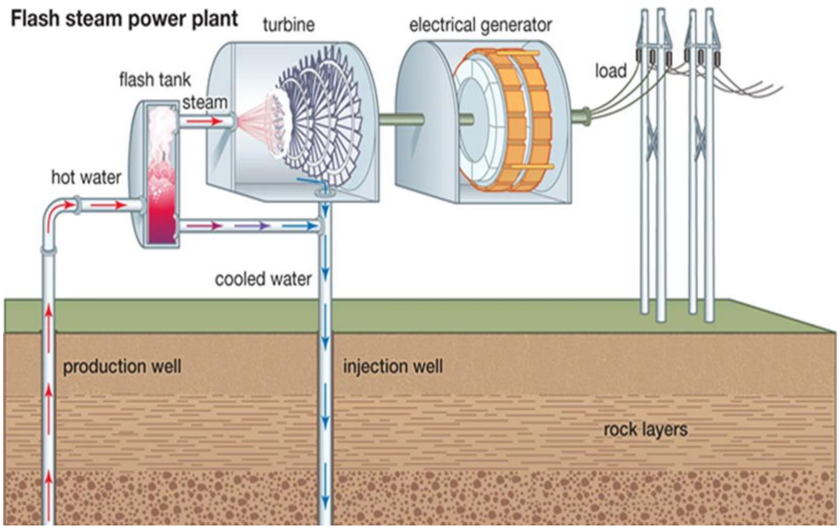


Source: Britannica

2.2.2 Flash steam geothermal power plants

Flash steam power plants are the most common type of geothermal power plants. They pump hot water from the geothermal reservoir to a lower pressure environment, causing the water to "flash" into steam, which then drives turbines to generate electricity. Figure 2.2 illustrates the operation of a flash steam geothermal power plant.

Figure 2.2*: *Flash steam power plant



Source: Britannica

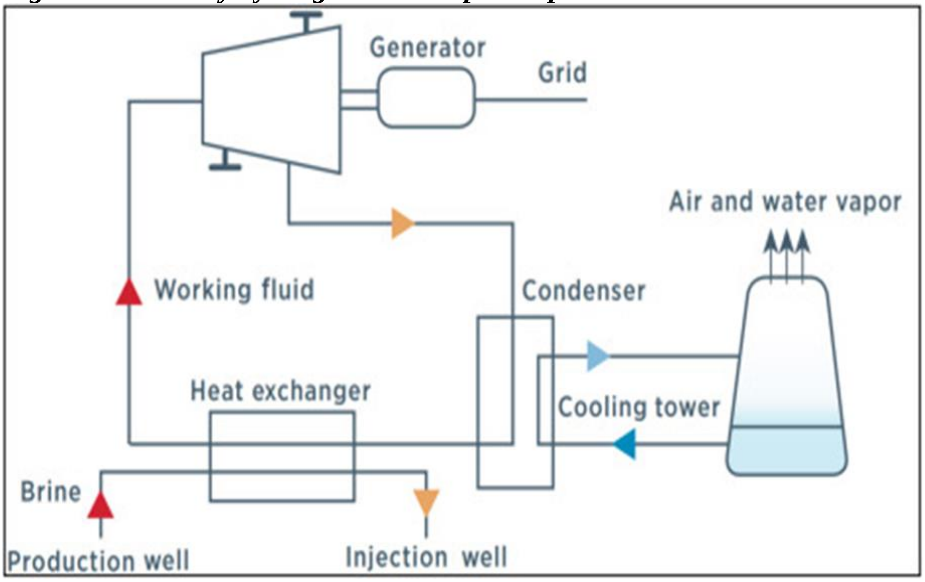
2.2.3 Binary cycle geothermal power plants.

Binary cycle power plants use a secondary fluid with a lower boiling point than water (example, ammonia or isopentane) to extract heat from the geothermal fluid. The secondary fluid is vaporized and used to turn turbines, while the geothermal fluid itself is reinjected into the reservoir.

The technology is gaining popularity in geothermal energy generation due to its environmental advantages and ability to harness lower-quality heat sources. This technology operates with minimal carbon dioxide emissions, making it a cleaner alternative to traditional fossil fuels and an appealing option for reducing greenhouse gas emissions. By using high-temperature geothermal water to heat a working fluid, binary cycle plants can generate power from more common, moderate geothermal resources. Recent expansions in Japan have demonstrated growing interest in this eco-friendly technology, as it aligns with global goals for sustainable energy development and environmental protection.

Social acceptance of geothermal energy is also increasing, particularly with innovations that enhance its efficiency and flexibility. The sector has maintained steady growth, averaging a 3.5% increase per year since 2000, as communities become more receptive to the environmental and economic benefits of geothermal power. The two cycles of a binary power plant are shown in Figure 2.3.

Figure 2.3: Binary cycle geothermal power plant



Source: Science direct

2.3 Geothermal energy is a source of clean energy.

Geothermal energy presents several advantages in terms of environmental conservation. Geothermal power plants emit very low levels of greenhouse gasses compared to fossil fuel plants, with primary emissions being steam and small amounts of non-condensable gasses, which helps reduce the overall carbon footprint and mitigate global warming. These plants also occupy relatively small land areas compared to other renewable energy sources like solar or wind power plants, reducing habitat disruption and preserving natural landscapes and resources. Additionally, geothermal power plants use significantly less water than conventional power plants, which is crucial in areas where water is scarce (Cahyono, 2010).

Table 2.1: tCO/MWh emission from geothermal energy and fossil fuel.

	Geothermal (binary technology)	Coal	Petroleum	Natural Gas
Emissions in (tCO/MWh)	0.0816	0.9662	0.7076	0.4672

Source: World Geo Congress report of 2010

Geothermal energy generation aligns with the goals of the Paris Agreement, which aims to limit global warming to well below 2°C above pre-industrial levels (Kobayakawa, 2021). According to Kulasekara & Seynulabdeen (2019), with the low greenhouse gas emissions, geothermal energy supports the decarbonization of the energy sector, helping countries meet their emission reduction targets. Unlike some other renewables like solar and wind, geothermal energy provides a stable and reliable source of power, ensuring a consistent supply of low-carbon energy crucial for transitioning away from fossil fuels. By developing domestic geothermal resources, developing countries can reduce their dependence on imported fossil fuels, enhancing energy security and aligning with the goals of sustainable development and resilience outlined in the Paris Agreement (Fridleifsson et al., 2008).

Investing in geothermal energy also drives economic growth through the development of new technologies and industries, creating jobs in the construction, operation, and maintenance of geothermal plants, and contributing to sustainable development (Kurek et al., 2021) . Delina (2017) explains that the Paris Agreement emphasizes support for developing countries in their transition to clean and sustainable energy, and many developing countries have significant geothermal potential. Harnessing this energy can aid in their sustainable development and economic growth while reducing global emissions since energy is the main driver of economic development. Overall, geothermal energy offers significant environmental benefits, supports the transition to a low-carbon economy, and helps mitigate climate change by providing a reliable, sustainable, and low-emission source of energy (Kulasekara & Seynulabdeen, 2019).

However, geothermal energy is not without its environmental challenges. Land use for geothermal installations can affect local ecosystems, and the extraction process can involve significant water usage, potentially affecting local water resources. Induced seismicity, or small earthquakes triggered by geothermal drilling and fluid injection, another concern that has gained attention over time. Ongoing studies focus on mitigating these issues through advanced environmental management practices and improved geothermal technologies (Bošnjaković et al., 2019). Ensuring the sustainable use of geothermal resources will be crucial in maintaining their viability as a long-term renewable energy source and maximizing their environmental benefits.

2.4 Carbon Trading

Carbon trading, also known as emissions trading, is a market-based approach to controlling pollution by providing economic incentives for reducing the emissions of pollutants, specifically greenhouse gases. Under carbon trading systems, a limit (cap) is set on the total amount of GHGs that can be emitted by all participating entities. These entities, often companies or countries, are allocated or can purchase a certain number of carbon credits or allowances, each permitting the holder to emit a specific amount of GHGs, typically one ton of carbon dioxide equivalent (CO2e). Entities that reduce their emissions below their allowance can sell excess credits to others who need to offset their excess emissions, thus encouraging overall emissions reductions in a cost-effective manner (Jia & Lin, 2020).

Carbon trading plays a significant role in advancing renewable energy generation through several mechanisms. By assigning a monetary value to carbon reductions, carbon trading fosters financial incentives that encourage investments in renewable energy initiatives. Projects such as wind, solar, and geothermal power can earn carbon credits by displacing fossil fuel-based energy sources and curbing greenhouse gas emissions, which can then be traded in carbon markets to generate additional revenue for the renewable energy power plants. This financial boost not only enhances the economic viability of renewable projects but also attracts crucial investment, particularly in regions where renewable energy might be economically challenging (Huang et al., 2023).

Moreover, carbon trading promotes market expansion for renewables by increasing the relative cost of carbon-intensive energy production, thereby positioning renewables as more cost-effective and competitive alternatives. In a policy context, integrating carbon trading into energy frameworks empowers governments to enforce emissions targets, thus supporting utilization of cleaner energy sources, aligning with global climate objectives, and reducing dependence on fossil fuels. Beyond economic gains, the synergy between carbon trading and renewable energy contributes to broader sustainability efforts, fostering environmentally sound practices that mitigate carbon footprints and combat climate change (Zhou, 2023).

Chapter 3. Methodology

Introduction

This chapter describes the research methodology employed to analyze the potential of geothermal energy in Kenya in conjunction with carbon trading mechanisms. The approach combines qualitative research, case study analysis, and legal evaluation, providing an understanding of how carbon trading could enhance geothermal energy development in Kenya as well as how it aligns to the country's energy transformation goals. The ultimate aim is to offer informed policy recommendations that align with Kenya’s energy strategies and global climate goals.

3.1 Review of Kenya’s Energy Landscape and Strategic Goals

The first step in the research involved a review of Kenya’s current and projected energy mix. This analysis relied heavily on the Ministry of Energy’s *Least Cost Power Development Plan (LCPDP)* 2024 to 2043, which provides a blueprint for meeting the country's energy demands while minimizing costs. The LCPDP highlights the role of various energy sources—hydropower, solar, wind, geothermal, and fossil fuels—and sets forth strategies for achieving a diversified and reliable energy supply. By reviewing this plan, the study established a solid foundation for understanding Kenya’s strategic energy goals, including its commitment to sustainable development through the promotion of renewable energy sources such as geothermal power.

Geothermal energy holds a pivotal role in Kenya’s efforts to increase renewable energy capacity, reduce carbon emissions, and enhance energy security. With the country situated along the geologically active Rift Valley (the great rift valley), it possesses significant geothermal potential. However, this potential remains underutilized due to technical and financial challenges, including the high costs of exploration and drilling. This research recognizes that effective carbon trading could provide an additional revenue stream to offset these challenges, making geothermal projects more financially viable projects for both the government and private investors in the energy sector.

3.2 Legal and Regulatory Framework for Carbon Trading

Following the review of the energy landscape, the study focused on Kenya's legal and regulatory framework for carbon trading. This evaluation was essential to understand the existing policies, barriers, and opportunities for carbon market participation. Kenya is a signatory to several international climate agreements, including the Paris Agreement, which encourages nations to adopt carbon reduction strategies through mechanisms like carbon trading. However, despite the potential benefits of carbon markets, the study identified gaps in Kenya's regulatory environment, such as the absence of a national carbon-trading framework.

The analysis aimed to identify legal instruments that govern Kenya's participation in voluntary carbon markets and compliance with global emission reduction frameworks. This evaluation highlighted both facilitators, such as government incentives for renewable energy projects, and barriers, including policy fragmentation and a lack of institutional capacity to implement carbon trading schemes. The research also identified a need for enhanced coordination between energy sector stakeholders and environmental regulators to ensure that carbon trading mechanisms can be effectively integrated into Kenya's energy policy.

3.3 Case Study Analysis: Lessons from China and the European Union

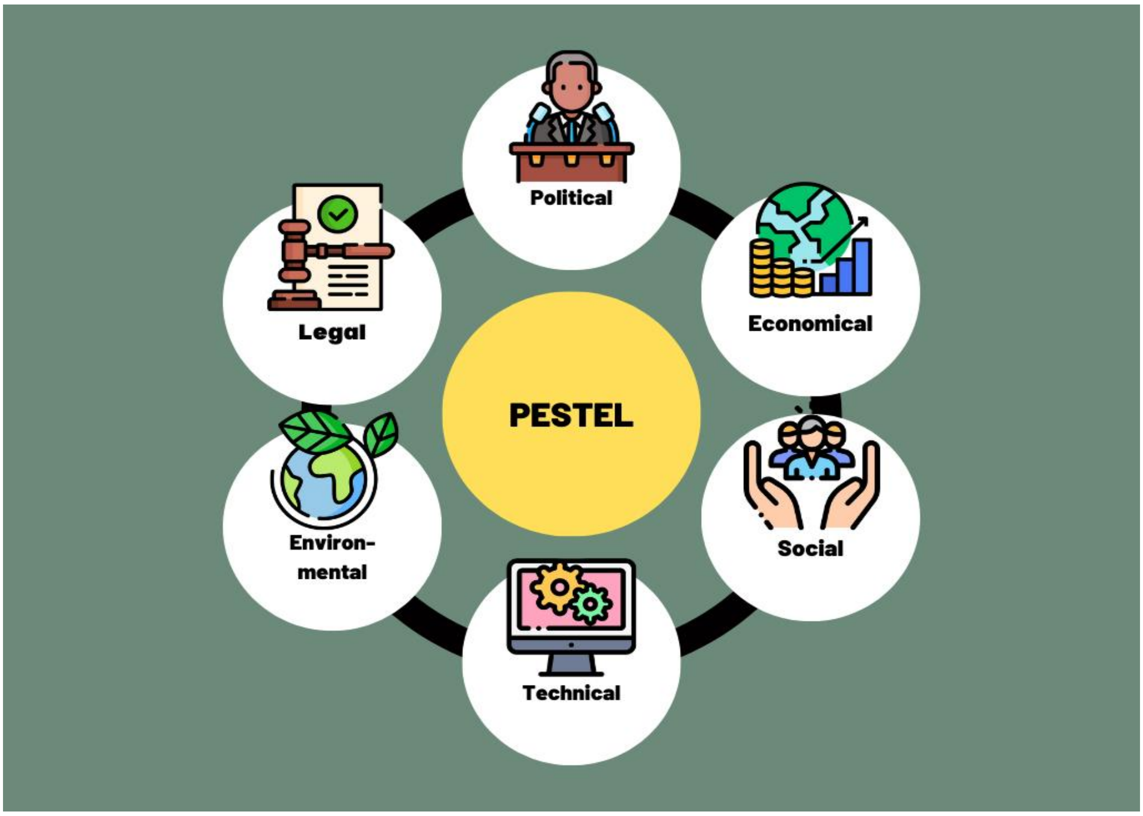
To gain insights into successful carbon trading schemes, the research examined case studies from China and the European Union (EU). These regions were selected due to their experience in designing and implementing carbon markets. The EU's Emissions Trading System (ETS) is the largest carbon market globally, offering valuable lessons on operational frameworks, market stability mechanisms, and policy instruments that encourage emission reductions. China's national carbon market, although relatively new, provides insights into the challenges and opportunities faced by developing countries in establishing carbon markets.

Both case studies illustrated the importance of strong regulatory frameworks, transparent governance structures, and market-based incentives to encourage participation from energy producers. The lessons drawn from these regions inform how Kenya could design its carbon trading policies to optimize revenue generation for geothermal projects. The case studies also provided an understanding of the potential challenges Kenya might face, such as market volatility and fluctuating carbon prices, which could impact the financial sustainability of geothermal investments.

3.4 Analysis: PESTEL Analysis Tool

To further analyze the feasibility and prospects of geothermal energy development under carbon trading, the study employed PESTEL analysis tool. These tool offered an assessment of external factors that influence the energy sector. The PESTEL analysis evaluates six key dimensions: political, economic, social, technological, environmental, and legal factors affecting the development of geothermal energy and carbon trading initiatives in Kenya, Mohamadi & Mohamadi. (2021). politically, the Kenyan government has demonstrated support for renewable energy through policies and incentives. Economically, however, the high capital costs associated with geothermal drilling remain a significant barrier, necessitating additional revenue sources such as carbon trading. Social factors include community engagement and public acceptance of geothermal projects, which are critical to their success. According to Merem et al. (2019), technologically, Kenya has made advancements in geothermal exploration among African countries, but further investment is needed to enhance efficiency. Environmental considerations are paramount, as geothermal energy supports Kenya's efforts to reduce greenhouse gas emissions and mitigate climate change (Rotich et al., 2024). Finally, the legal dimension highlights the importance of establishing a robust regulatory framework to facilitate carbon market participation. Figure 3.1 illustrates the summary of the study areas under the PESTEL analysis tool.

Figure3.1: The PESTEL analysis tool.



3.5 Data Collection and Sources

The research relied on secondary data from reputable sources to support its analysis. Key sources included reports from the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), Kenya's Ministry of Energy, the Kenya Geothermal Development Company (GDC), Kenya Power (KPLC), and the Kenya Energy Generation Company (KenGen). These organizations provide critical data on Kenya's energy production capacities, carbon emissions, and renewable energy development trends. Additionally, policy documents and market reports were consulted to understand the evolving landscape of carbon trading and its potential impact on Kenya's geothermal sector.

The data collected covered multiple dimensions, including:

- Current geothermal capacity and production trends in Kenya.

- Policies governing renewable energy and carbon trading.
- International benchmarks for carbon market participation.
- Economic factors affecting the financial sustainability of geothermal projects.

3.6 Data Analysis

The data collected from various sources was analyzed using the PESTEL analysis tool to provide a nuanced understanding of Kenya's geothermal sector. The PESTEL analysis identified key external factors shaping the energy market. The PESTEL analysis evaluated six key dimensions: political, economic, social, technological, environmental, and legal factors affecting the development of geothermal energy and carbon trading initiatives in Kenya, Mohamadi & Mohamadi. (2021).

The study also considered the energy trilemma the challenge of balancing energy security, affordability, and sustainability. Geothermal energy, if well developed, offers a solution to this trilemma by providing a stable and clean energy source. However, the high capital costs, social acceptance of geothermal projects, and regulatory uncertainties surrounding carbon trading present obstacles that must be addressed through policy interventions.

3.7 Limitations of the Study

While this research provides valuable insights, it acknowledges several limitations. One key limitation is the economic benefit analysis (CBA), which does not fully capture the financial complexities involved in geothermal development. Drilling costs in particular are substantial and have a significant impact on the financial viability of projects. The study also relies on secondary data sources, which may limit access to the most recent information on energy trends and carbon trading policies. These limitations highlight the need for further research to refine the economic projections and policy recommendations presented in this study.

3.8 Policy Recommendations

Based on the findings from the analysis, the study offers several policy recommendations to enhance the integration of carbon trading mechanisms in Kenya's geothermal sector.

Schedule of works

The study will begin with a literature review focused on geothermal energy technologies. It will examine existing research on the subject, with a specific focus on Kenya’s geothermal energy landscape. Additionally, it will explore case studies of successful geothermal projects in both Kenya and other countries. These examples will highlight how geothermal energy can be integrated with emerging frameworks like carbon trading, providing insights into the potential benefits for the energy sector.

Next, the data collection phase will involve gathering relevant information from various reputable sources. These include global organizations such as the International Renewable Energy Agency (IRENA) and the International Energy Agency (IEA), as well as local Kenyan institutions like the Ministry of Energy, the Geothermal Development Company (GDC), and Kenya Electricity Generating Company (KenGen). Any other relevant sources that can contribute to a comprehensive understanding of geothermal development will also be considered.

Once the data is gathered, it will undergo analysis to identify critical patterns and insights. This phase will involve the use of PESTEL analysis tool. The analysis will help assess the external factors affecting Kenya’s geothermal energy sector; view of external factors such as political, economic, and environmental influences and evaluate how they impact the sector's development. It will also examine the "energy trilemma," balancing energy security, sustainability, and affordability.

The insights drawn from this analysis will be synthesized into conclusions and policy recommendations. The goal is to propose strategies that can enhance the growth of geothermal energy while ensuring long term environmental sustainability. Special attention will be given to policies that support the integration of carbon trading mechanisms, fostering alignment with global energy goals.

Chapter 4. Results

Introduction

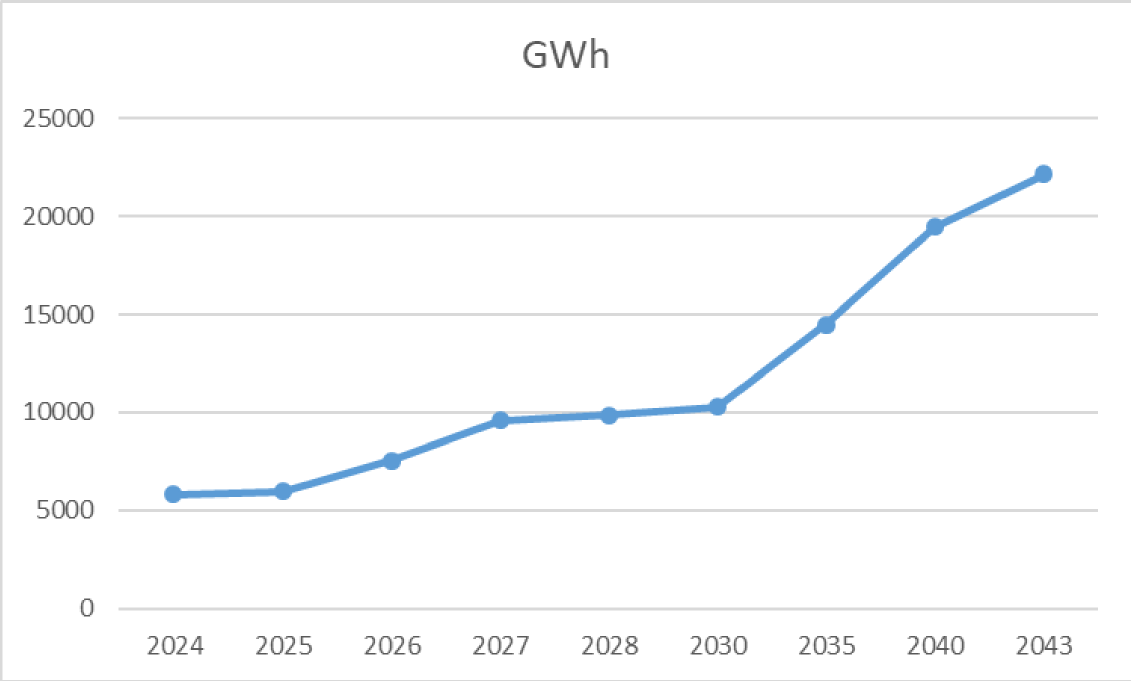
Kenya is positioning itself as a leader in geothermal energy within its energy mix, striving to balance increased power generation with environmental protection and social benefits. This chapter explores Kenya's current geothermal initiatives, focusing on the projected expansion of geothermal capacity through to 2043 and the potential environmental gains from transitioning to low-emission binary cycle technology. Comparisons between Kenya's current flash steam technology and a more sustainable binary systems technology illustrate the environmental advantages, including substantial reductions in carbon emissions, which would qualify for carbon credits and increase revenues to the power plants projects making investments for the same more attractive. With recent amendments to Kenya's Climate Change Act, this chapter will review the regulatory landscape in Kenya that aims to support carbon markets, enhancing project acceptance and encouraging further investment in geothermal power. Case studies from the European Union and China provide additional insights into emissions trading systems, offering valuable lessons for Kenya's journey toward sustainable energy growth and robust climate finance mechanisms.

Kenya's current state

Projected utilization of the geothermal technology in the energy mix

Geothermal energy is currently the most reliable base load of electricity generation in Kenya and is projected to play a crucial role in Kenya's energy future, with estimates indicating it will constitute around 36% of the nation's total effective capacity by 2043 according to the LCPDP report. This anticipated growth reflects Kenya's strategic investment in geothermal power as a reliable and renewable source, particularly given the extensive geothermal potential in the great Rift Valley. Compared to other energy sources, geothermal offers consistent base-load power, making it more dependable than solar or wind, which are subject to weather variability. Additionally, as Kenya seeks to reduce its dependence on fossil fuels and limit carbon emissions, geothermal energy provides a cleaner alternative that aligns with the country's climate goals. This shift toward geothermal dominance in the energy mix not only supports Kenya's sustainability agenda but also enhances energy security by diversifying the sources of power generation. Table 4.1 and graph 4.1 show the current and projected amount of energy generated from geothermal according to the LCPDP report.

graph 4.1: Geothermal power GWh (2024-2043)



Source: Kenya LCPDP report 2023-2024

Table 3.1: projected emission if the current technology is applied for the additional power plants until 2043.

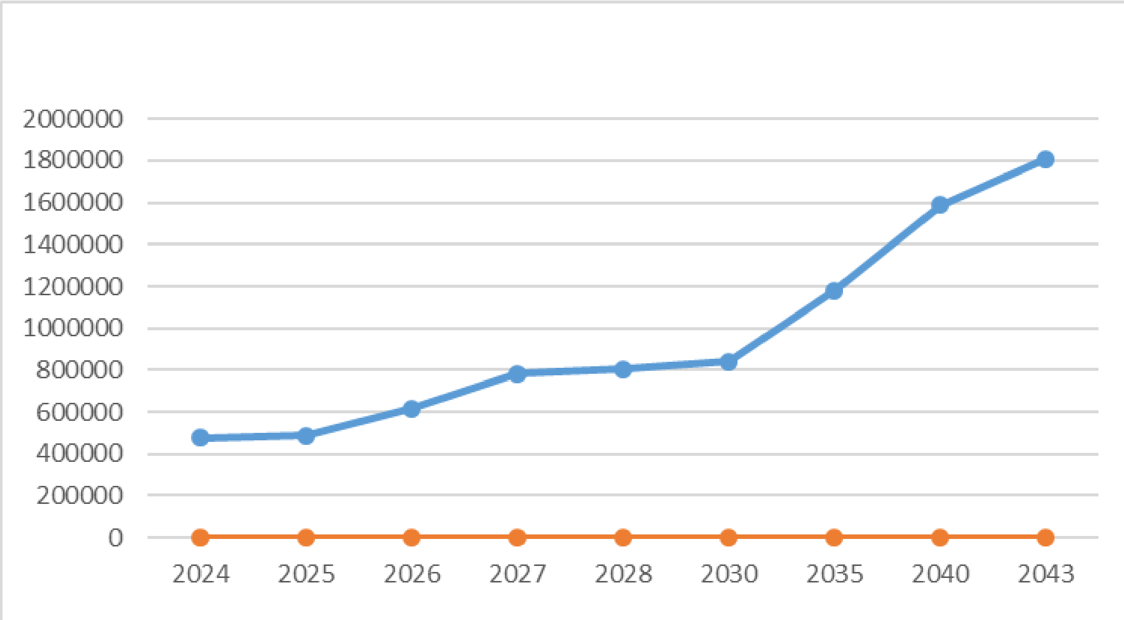
	2024	2025	2026	2027	2028	2030	2035	2040	2043
GWh	5815	5962	7554	9596	9846	10300	14480	19472	22143
MWh	5815000.0	5961904.7	7554166.7	9596000.0	9845833.4	10300000.0	14480000.0	19472000.0	22143478.3
Emissions in tones	474504	486491	616420	783034	803420	840480	1181568	1588915	1806908

Binary geothermal technology has a significant advantage over flash steam systems in terms of emissions, as it can achieve near-zero emissions, unlike flash systems that release notable amounts of carbon dioxide and other gases. In a binary system, the geothermal fluid is contained in a closed-loop cycle, where it transfers heat to a secondary working fluid with a lower boiling point, which then vaporizes to drive a turbine. This closed process ensures that geothermal fluids, which may contain dissolved gases, never come into direct contact with the atmosphere. By contrast, flash systems bring geothermal fluids directly to the surface, where they release steam and any dissolved gases, including CO_2, into the air. Therefore, adopting binary technology can dramatically reduce the environmental impact of geothermal energy generation, aligning well with zero-emission goals and making it ideal for regions aiming to minimize their carbon footprint**.** Table 4.2.: shows the projected emission if binary technology is applied for the additional geothermal power plants until 2043.

Table 4.2: projected emission if binary technology is applied for the additional geothermal power plants until 2043.

	2024	2025	2026	2027	2028	2030	2035	2040	2043
Emissions in (tCO/MWh)	 474504	486491. 4222	616420. 0005	783033. 6	803420. 0064	840480. 0006	118156 8	158891 5.2	180690 7.827
	0	0	0	0	0	0	0	0	0

Graph 4.2: Emissions in (tCO/MWh) flash steam technology and binary technology (2024-2043)



(Emissions in tCO/MWh) Flash steam technology

(Emissions in tCO/MWh) binary power plant technology

Extra Benefits if Binary Power Plant Technology is Adopted for the New Power Geothermal Plant Projects

Kenya stands to gain additional revenue through carbon credits, and adopting binary technology could further increase marginal profits, enabling greater investment in geothermal energy development. Table 4.3highlights the project's revenue gains.

Table 4.3 Total revenue forgone if the current flash system technology is used for the additional geothermal power plants.

	2024	2025	2026	2027	2028	2030	2035	2040	2043

Aditional C02 emmission from 2024-2043	474504	486491	616420	783033	803420	840480	1181568	1588915	1806907
Tolal revenue forgone in Euros (millions)	39	40	51	65	67	70	98	13	15

- Rf= C* x Pc
    - Rf: revenue forgone
    - C*: Amount of carbon released
    - Pc: Price of carbon (*euros per tone of carbon*)

Review of legal framework for Kenya on carbon credit

In September 2023, Kenya's Climate Change Act, No. 11 of 2016, was amended to specifically regulate carbon markets in the country (National Assembly Bill of 20230). The revisions to the Act had the aim to provide guidance for the development and implementation of carbon markets in line with international obligations, establish policy direction, and create benefit-sharing mechanisms within the carbon market framework (Nkatha, 2023). The amended legislation introduces the creation of a national carbon registry in Kenya and provides for regulation of carbon credits trade. It requires all carbon trading projects to undergo mandatory environmental and social impact assessments in accordance with Kenya's environmental laws. Further, the amendments introduced community development agreements to manage the relationship and obligations between project proponents and the communities affected by carbon trading projects. (Kenya Law Society 2023)

Generally, the regulation of Kenya's carbon market is progressing well. While the substantive law has been enacted, the enabling regulations are yet to be published and presented to parliament. From a practical standpoint, setting up the carbon trading registry and other administrative functions may take time. However, with Kenya leading in climate change diplomacy, renewable energy transition, and climate finance access, there is strong political will to establish robust carbon markets. This will be expected to increase revenues for renewable energy power plants, making investment for the same attractive reducing investment in fossil fuel powered plants. Kenya's high potential in geothermal energy being a renewable source will upscale the geothermal energy technologies in the country.

With regulations governing the distribution of carbon credit proceeds to host communities, these communities are expected to benefit more from future projects. This, in turn, will enhance project acceptance, as illustrated in Table 4.4.

Table 4.4 Additional revenue to community projects (if the law on carbon credit is passed by parliament and Binary technology is adopted)

	2024	2025	2026	2027	2028	2030	2035	2040	2043

Total additional revenue (in Euros)	39596732	40597067	51439435	65343120	67044339	70136947	98600290	132592876	150784073
Additional revenue to the host community(≈millions)	10	10	13	16	17	18	25	33	38

- *Rc= Rt x 0.25*
    - Revenue to the community
    - Rt=total revenue
    - Therefore additional revenue to the community will be*(25% of additional revenue from carbon credit)*

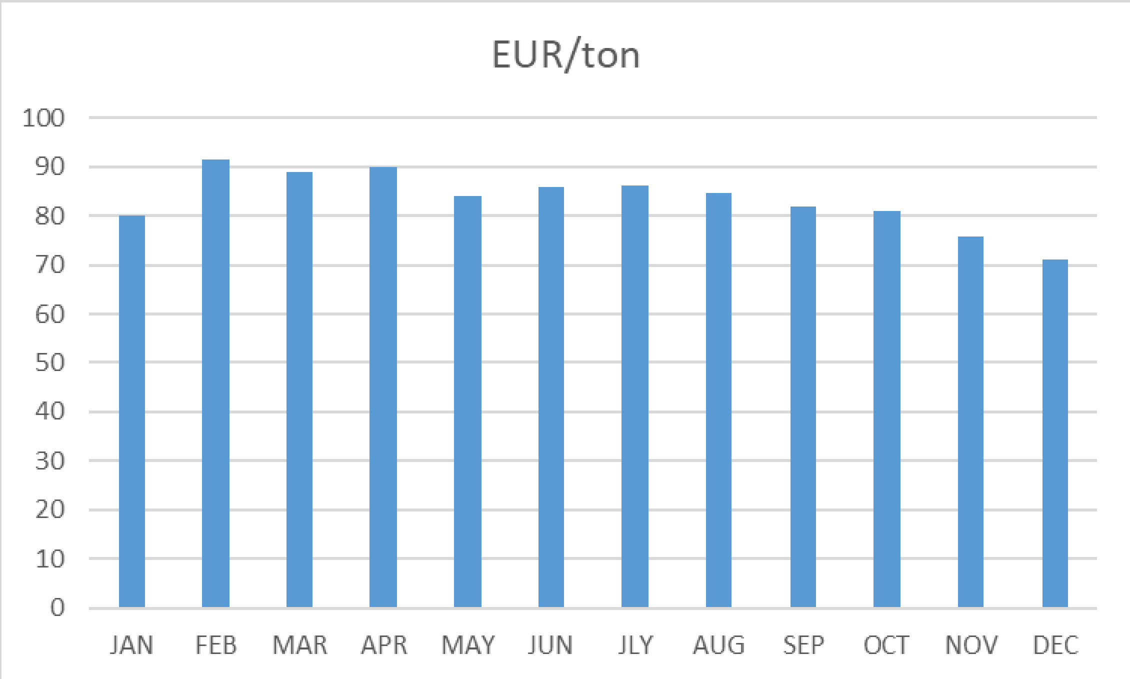
Review of case studies

1. European Union

Established in 2005, the European Union Emissions Trading System (ETS) became the world's first emissions trading mechanism, encompassing sectors like electricity generation, energy-intensive industries such as cement, and aviation. The ETS's development was implemented in four phases. Phase one (2005-2007) acted as a pilot phase, covering electricity generation and energy-intensive industries, where many emission allowances were freely allocated, with non-compliance penalties set at €40 per ton. Despite a surge in carbon trading volume, incomplete emission data led to a surplus of allowances, causing their price to fall to zero in 2007. Phase 2 (2008-2012) aligned with the Kyoto Protocol commitment period, prompting tighter allowance caps and increased penalties for non-compliance.

During Phase 3 (2013-2020), significant reforms were implemented in the ETS, including the shift to auctioning as the primary method for allocating allowances and the extension of coverage to more sectors. In Phase 4 (2021-2030), the system faced proposed revisions to align with the EU Climate Law, aiming for a 43% reduction in emissions compared to 2005 levels. This phase also introduced an annual reduction of allowances by 2.2% starting in 2021, marking a continuous effort to tighten emissions control and drive sustainable practices across the EU (Serina et al., 2024).

The graph 4.3 shows the average market price of carbon in Europe for the year 2023 in EUR/ton of CO2. The average price for the year 2023 is 83.44868 EUR/ton (International Carbon Action Partnership 2024).



Graph 4.3: carbon price of Europe in 2023

2. China

China's energy sector has undergone significant transformation through the adoption of carbon trading systems aimed at reducing greenhouse gas emissions. The country's carbon market, the largest globally, plays a pivotal role in its efforts to peak carbon emissions by 2030 and achieve carbon neutrality by 2060. This market offers renewable energy sectors, including geothermal energy, substantial advantages, particularly through the monetization of carbon credits. These financial incentives are essential for supporting clean energy development and facilitating the transition away from fossil fuels (Wang et al., 2015).

China launched its national carbon trading system in 2021, building on pilot programs in seven regions. The power sector, responsible for nearly 40% of the country's total carbon emissions, was the initial focus (Serina et al., 2024). This prioritization underscores the sector's potential to significantly reduce emissions. Since its inception, the carbon market has demonstrated remarkable progress, with over 179 million tons of carbon allowances traded by the end of 2021, valued at 7.68 billion RMB. Renewable energy projects, including geothermal energy, have been significant beneficiaries of this system due to their low emissions and long-term sustainability. The Ministry of Ecology and Environment reports that renewable energy projects account for a substantial share of Certified Emission Reductions (CERs) in China's carbon market.

Geothermal energy, recognized for its reliability and minimal emissions, benefits greatly from the carbon credit system. These credits create financial incentives by providing revenue streams that offset the high upfront costs typically associated with geothermal projects, improving their overall financial viability. Carbon trading enables geothermal projects to generate income by selling excess carbon credits, which are derived from the difference between actual emissions and baseline levels set for conventional energy sources. For instance, a geothermal power plant that emits 100,000 fewer tons of CO_2 annually compared to a coal-fired plant can monetize these reductions through the carbon market (Wang et al., 2015).

The emissions gap between geothermal and coal-fired plants illustrates this potential. While geothermal plants typically emit around 50 grams of CO_2 per kilowatt-hour (gCO_2/kWh), coal-fired plants emit 800–900 gCO_2/kWh. A 100 MW geothermal plant can save approximately 700,000 tons of CO_2 annually compared to a coal-fired plant, generating significant revenue through carbon credit sales in both compliance and voluntary markets. These credits provide an ongoing income stream that supports not only the financial sustainability of geothermal projects but also their expansion and technological advancement.

In addition to generating revenue, carbon credits lower compliance costs for renewable energy generators. Geothermal plants, which inherently produce fewer emissions, often receive free or discounted allowances within compliance markets. These allowances can be monetized, further enhancing their financial position. This cost advantage allows geothermal operators to allocate resources to scaling their operations and maintaining their competitive edge over fossil fuel-based energy producers.

The financial mechanisms of the carbon market also make geothermal energy more attractive to private and institutional investors. The additional income generated through carbon credits creates a predictable revenue stream, which reduces investment risk and encourages capital flow into geothermal projects. Data from China's carbon market underscores this dynamic, as renewable energy projects consistently attract significant investment due to their profitability and alignment with national and global decarbonization goals.

Geothermal energy's low emissions profile further bolsters its competitive advantage. Unlike fossil fuel-based energy sources, geothermal plants can sell surplus credits or use them to offset emissions from other operations, reinforcing their market position. By leveraging these credits, geothermal operators gain financial flexibility, enabling them to enhance efficiency and scale production. This strategic positioning is vital for contributing to China's broader energy transition goals.

The advantages of geothermal energy in China's carbon market are supported by compelling data. The carbon intensity of geothermal power averages 50 gCO_2/kWh, significantly lower than coal and natural gas plants, which emit 800–900 gCO_2/kWh and 400–500 gCO_2/kWh, respectively (Zhang et al., 2020). This contrast highlights geothermal energy's potential to drive meaningful emissions reductions. A single geothermal project can generate substantial carbon credit revenue, which can then be reinvested into expanding capacity, further reducing emissions, and diversifying China's energy portfolio.

As China’s carbon market evolves, opportunities for geothermal energy are expected to grow. The planned expansion of the carbon trading system to include industries beyond power generation, such as steel and petrochemicals, will likely increase the demand for carbon credits. This broader market engagement will enhance the value of credits generated by geothermal projects, strengthening their financial sustainability.

The continued maturity of carbon credit mechanisms will further improve the financial outlook for geothermal energy projects. As the market expands, geothermal operators can take advantage of these mechanisms to fund technological advancements, enhance operational efficiency, and scale their contributions to China’s renewable energy goals. These developments will also attract a wider range of stakeholders, from government agencies to private investors, fostering collaborative efforts to accelerate the adoption of geothermal energy.

China’s carbon trading system exemplifies a strategic approach to de-carbonization, offering renewable energy sectors like geothermal a powerful financial tool. Carbon credits bridge the gap between the high initial costs of geothermal projects and their long-term sustainability, providing consistent revenue streams that promote growth and innovation (Hu et al., 2020). With its low emissions and proven reliability, geothermal energy is well-positioned to play a pivotal role in achieving China’s ambitious climate targets. As the carbon market continues to expand and mature, geothermal energy stands a chance to become significant in China’s clean energy future, demonstrating how effective carbon trading can drive sustainable development in the energy sector.

Chapter 5. Discussion

Carbon credits play a significant role in making green energy projects more financially viable by creating an additional revenue stream. This extra income helps to offset the initial costs of such projects, reducing the financial risks for investors and making green energy projects more attractive for funding. The monetization of carbon emissions reductions not only encourages investment but also supports the scaling of renewable energy technologies. Kenya can take advantage of carbon credits in funding of her future geothermal energy projects due to the very high geothermal energy potential in the country and consequently have a more reliable base load energy source.

Beyond investment, carbon credits incentivize innovation in clean technology by providing financial rewards for reducing emissions. This encourages companies and researchers to develop new, more efficient methods of harnessing renewable energy. As these technologies become commercialized, carbon credits help scale their deployment, making green energy solutions more widespread and affordable, thus fostering broader adoption.

Moreover, carbon credits contribute significantly to sustainable development by promoting job creation and infrastructure improvements, particularly in developing countries. They also support global environmental goals by incentivizing emissions reductions and biodiversity conservation. By aligning with international climate policies and enhancing corporate sustainability practices, carbon credits not only support the growth of global carbon markets but also enhance the reputation of companies committed to reducing their carbon footprints, playing a vital role in the global transition to a low-carbon economy.

PESTEL analysis

PESTEL analysis is a tool used to understand the external macro-environmental factors that could impact the success and development of energy projects in a country. The acronym PESTEL stands for political, economic, social, technological, environmental, and legal factors. In relation to geothermal energy projects in Kenya, PESTEL analysis will help in assessing the various external influences that can affect projects' viability, implementation, and long-term sustainability. Tables 5.1 and 5.2 show the PESTEL analysis for Kenya if the adoption of the new legislation of canon credit will be in place as well as if the binary technology is adopted. (Green color shows no action needed, Amber shows some minor action is needed, and Red shows adverse impact/major action needed.)

Table 5.1 PESTEL analysis (flash steam power plant technology)

Factor	**Kenyan context**	**Impact/action level**
Political	● The government is in support of environmental conservation and supports implementation of clean energy projects in the LCPDP report of 2024-2043. ● There is commitment to decarbonize the energy sector. ● The government has invested in geothermal energy technology innovation and has an annual budget for the same through GDC. ● Kenya aligns with the international climate policies.	
Economic	● Funding is available since it's a clean energy technology, thus able to access multilateral funding.	
Social	● Through initiatives such as social corporate responsibility and compensation of the host communities, there is less resistance to the geothermal energy projects. ● Due to the venting challenges of current technology, environmental activists tend to oppose the energy generation through geotherma technology at Olkaria. ● Discomfort to the tourists visiting the Hales Gate National Park due to the veneted steam that has hydrogen sulfide. ● Loss of cultural activities by the host communities that are involved in hunting and gathering as well as pastrolism. This is due to loss of ground cover resulting from acid rain in the area.	
Technological	● Technology is available locally with enough human resources. ● There are initiatives to export the geothermal technology to other countries in Africa (Kenyans are taking part in developing geothermal energy in Ethiopia). ● There exist arrangements to train more Kenyans locally through the research center at the Olkaria geothermal plant. ● Kenya is the first country in Africa and the seventh in the world in generating energy through geothermal energy technology.	

Environmental	• Geothermal energy is clean energy and therefore an environmentally friendly source of energy. • There is venting of excaess steam, resulting in the release of greenhouse gases, though it is not as significant as fossil fuels.	
Legal	• A law on carbon credits is in the final stages of the legislative process and, if passed, will result in significant growth in renewable energy generation, including geothermal energy, through the generation of extra income streams for future power plant projects.	

Table 5.2: PESTEL analysis (Binary cycle power plant technology)

Factor	**Kenyan context**	**Impact/action level**
Political	• The government is in support of environmental conservation and supports implementation of clean energy projects in the LCPDP report of 2024-2043. • There is a commitment to decarbonize the energy sector. • The government has invested in geothermal energy technology innovation and has an annual budget for the same through GDC. • Kenya aligns with the international climate policies.	
Economic	• Being a developing country, funding of energy projects is a challenge; therefore, the Kenyan government depends on external funding for her energy projects. Carbon credits therefore will play a significant role in lowering the cost of project development as well as reducing risk and, as a result, attract investment in geothermal energy technology.	
Social	• Through initiatives such as social corporate responsibility and compensation of the host communities, there is less resistance to the geothermal energy projects. If the new law of carbon credit is passed and the share to	

	the host community is increased from 10% to the proposed 25%, then future projects will be more accepted by locals. ● Due to the venting challenges of current technology, environmental activists tend to oppose the energy generation through geotherma technology at Olkaria. By adopting the binary technology, future projects will experience no resistance since the risk could have been mitigated.	
Technological	● Technology is available locally with enough human resources. ● There are initiatives to export the geothermal technology to other countries in Africa (Kenyan engineers through KenGen are taking part in developing geothermal energy in Ethiopia). ● There exist arrangements to train more Kenyans locally through the research center at the Olkaria geothermal plant. ● Kenya is the first country in Africa and the seventh in the world in generating energy through geothermal energy technology. ● There will be no loss of energy due to venting by applying binary technology.	
Environmental	● Geothermal energy is clean energy and therefore an environmentally friendly source of energy. ● Adoption of the binary technology will minimize venting, thus resulting in zero emissions of GHGs.	
Legal	● A law on carbon credits is in the final stages of the legislative process and, if passed, will result in significant growth in renewable energy generation, including geothermal energy, through the generation of extra income streams for future power plant projects.	

A PESTEL analysis (Political, Economic, Social, Technological, Environmental, and Legal) provides insights into the factors that influence the adoption and success of Flash system technology and binary system technology in Kenya. Politically, Kenya is committed to decarbonizing its energy sector, with strong support from the government for clean energy initiatives outlined in the Long term Least Cost Power Development Plan (LCPDP). The government's backing for geothermal energy is evident through investments via the Geothermal

Development Company (GDC) and alignment with international climate goals, ensuring that geothermal remains a priority for national energy development.

Economically, flash steam technology has access to multilateral funding due to its established status, whereas binary cycle technology faces higher development costs. However, Kenya's reliance on external funding for energy projects and the potential for carbon credits currently being discussed in the legal framework could help solve the funding challenges and reduce the cost of geothermal projects. If passed, carbon credits could attract more investment, making binary cycle technology more financially viable.

Socially, Kenya's geothermal energy projects benefit from corporate social responsibility (CSR) efforts that ensure compensation for host communities, minimizing resistance. However, flash steam technology has faced opposition due to environmental concerns, such as hydrogen sulfide emissions from vented steam. Binary cycle technology, by contrast, eliminates this issue by preventing steam venting, addressing environmental and social concerns more effectively.

Technologically, Kenya has a strong capacity to support both technologies, with a wealth of trained engineers and researchers. The country is a leader in geothermal energy in Africa and plays a key role in exporting knowledge to neighboring countries. Binary cycle technology offers an edge over flash steam, as it minimizes energy loss by not venting steam, thus improving efficiency and reducing environmental impact.

Environmentally, both geothermal technologies are clean energy sources that help reduce greenhouse gas emissions compared to fossil fuels. However, binary cycle technology is particularly advantageous as it eliminates steam venting, resulting in zero emissions of greenhouse gases. This makes binary cycle technology a more environmentally sustainable option for Kenya's long-term energy needs.

Finally, Kenya's legal framework supports geothermal energy development. The carbon credits law, which is in the final stages of the legislative process, will provide an additional revenue stream for future geothermal projects, making them more attractive for investors and beneficial for host communities.

In conclusion, the PESTEL analysis highlights the significant potential of geothermal energy in Kenya, with both flash steam and binary cycle technologies contributing to the country's energy security and sustainable development goals. However, binary cycle technology stands out as the more environmentally and socially acceptable option, addressing key challenges such as steam venting and emissions. With continued government support, economic incentives like carbon credits, and advancements in technology, geothermal energy is poised to play a central role in Kenya's renewable energy future.

Chapter 6. Conclusion

Kenya's geothermal energy sector holds great potential for driving the country's transition to a low-carbon economy, especially with the projected increase in geothermal power generation over the next two decades (2024-2043). Graph 4.1 shows the increasing role of geothermal in Kenya’s energy mix, supporting the government’s decarbonization goals.

From an environmental standpoint, adopting binary technology for geothermal energy generation is highly advantageous. Graph 4.2 illustrates the significant reduction in carbon emissions when binary technology is applied compared to the current flash steam technology. Binary technology mitigates the venting of harmful gases such as hydrogen sulfide, making geothermal power cleaner and better aligned with Kenya’s climate goals.

The amendment of Kenya's Climate Change Act (2023) to regulate carbon markets enhances the prospects for geothermal investments by facilitating access to carbon credits. This creates an additional revenue stream that can be channeled into new geothermal projects, reducing the reliance on fossil fuel-based power plants. Furthermore, Kenya’s geothermal potential positions it as a leading player in renewable energy, not just in Africa but globally.

Legal and regulatory frameworks are progressing favorably, with the carbon credit legislation expected to boost renewable energy projects. As demonstrated by the successful carbon markets in the European Union and China, Kenya could leverage these frameworks to attract investments, scale geothermal technology, and create sustainable economic benefits.

Recommendation:

To advance Kenya's geothermal sector sustainably, this section recommends three strategic measures. Through the adoption of binary geothermal technology Kenya will achieve the targets of reducing emissions in energy generation, further the prioritizing carbon credit legislation can attract investment in renewable energy. Addressing social and environmental impacts will support community welfare and preserve local ecosystems. Expanding funding and training programs strengthens Kenya’s expertise and leadership in geothermal energy. Lastly, aligning with global carbon market trends will enhance Kenya’s revenue generation and ensure equitable community benefits. Together, these actions will boost Kenya's geothermal growth and climate goals.

1. Adopt Binary Technology for New Geothermal Projects: The shift to binary technology is crucial for Kenya’s energy sector. It significantly reduces emissions (as shown in Graph 4.2) and addresses concerns related to environmental pollution, making geothermal energy more environmentally sustainable.
2. Implement carbon credit legislation swiftly: The finalization and implementation of carbon credit legislation should be prioritized. This will create a robust carbon market that can fund future geothermal projects and increase the attractiveness of investments in renewable energy.

3. Monitor carbon market trends globally: Learning from established carbon markets, Kenya should continuously refine its carbon market mechanisms to ensure they align with international standards and maximize revenue generation from carbon credits. This includes establishing a transparent carbon registry and facilitating community engagement to ensure equitable benefit sharing.

By adopting these measures, Kenya can ensure that geothermal energy continues to grow as a key component of its energy mix while contributing to both national economic development and global climate objectives.

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