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The articles must be well researched and written to appeal to our high-end readers in Kenya and beyond.

The IEK Editorial Board reserves the right to edit and publish all articles submitted, in line with the standing editorial policy. All articles should be in Word document format, 500-700 words, font type Times New Roman and font size 12.

Send your article today, and get a chance to feature in the magazine!

Send your article to: **editor@iekenya.org**

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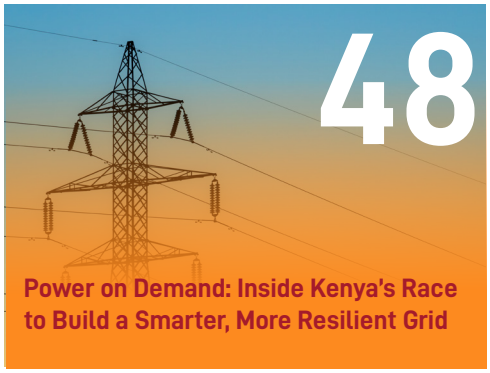
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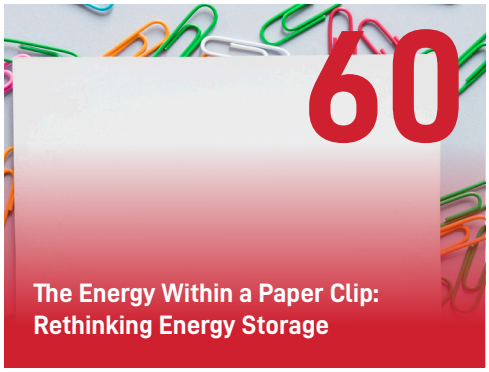


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In this Issue









4	Message from the Editor
6	Message from the President
8	Message from the Honorary Secretary
9	Powering Africa's Future: Engineering Clean Energy, Manufacturing, and Local Innovation
13	Beyond Baseload: Integrating Nuclear Energy, Renewables and Storage for Kenya's Sustainable Energy Future
18	Engineering Education, Applied Research and Technical Skills: Interview Insights from the Technical University of Kenya (TUK)
22	Beneath the Rift: The Engineering Powering Kenya's Geothermal Future
25	Engineering Circularity: Rethinking Biomass, Energy and Industrialization in Kenya
28	Renewable Energy and Storage Engineering in Kenya: Opportunities and Challenges
32	Balancing the Breeze and the Sun: Inside Kenya's Renewable Grid Challenge
36	ANN-Based Short-Term Load Forecasting with Reliability Impact Assessment for Power System
43	Power on Demand: Inside Kenya's Race to Build a Smarter, More Resilient Grid
46	The Importance of Quality and Counterfeit Awareness in Kenya's Renewable Energy Market
48	Power on Demawnd: Inside Kenya's Race to Build a Smarter, More Resilient Grid
50	Closing the Circular Loop through Integrated Biodigesters and Biomass Briquetting Systems for Waste-to-Energy
53	Driving Renewable Energy Innovation: The Role of Mechanical Engineering Research in Kenya's Clean Energy Transition
56	Engineering Kenya's Energy Transition: Making Every Unit of Energy Work Harder
60	The Energy Within a Paper Clip: Rethinking Energy Storage
64	Processing and Characterization of Blowroom Cotton Fibre Waste as a Potential Reinforcement for Polymer Composites
71	Off-Grid Electrification: Powering Rural Kenya
75	PICTORIAL REPORTS
82	Efficient Utilization of Geothermal Resource Through Simulation of a Binary Power Plant Using Brine From 105mw Project in Menengai Geothermal Field, Kenya.
90	From Importer to Innovator: Building Kenya's Renewable Energy Industry

Message From the Editor



Eng. Prof. Alex Muumbo, PE,FIEK

Dear Members and Readers,

Welcome to the 29th issue of Engineering in Kenya. This edition is devoted to Renewable Energy and Energy Storage Engineering, a subject that now sits at the centre of Kenya's economic ambition and the engineering profession's responsibilities.

Kenya has long been admired for the share of renewable sources in its electricity mix, from geothermal and hydro to a fast-growing portfolio of wind and solar. That success brings a new engineering question. It is no longer only how to generate clean power, but how to keep it stable, firm and affordable as variable sources take up a larger share of the system. Storage, grid integration, regulation, local manufacturing and skills are where that question will be answered, and they are the threads that run through this issue.

The issue opens with the grid. Leaders from the transmission, generation and distribution segments of the sector discuss the practical realities of balancing sun and wind: maintaining voltage and frequency stability, managing intermittency, and building a smarter, more resilient network. Alongside these conversations, our features look beneath the Rift Valley at the engineering behind Kenya's geothermal leadership, and beyond the grid to the mini-grids and battery systems bringing reliable power to rural communities.

Policy and regulation are given equal weight. Contributions from government, the regulator and the rural electrification agency set out the national roadmap, the licensing and standards framework for storage and renewables, and the work of connecting households and enterprises that the main grid has yet to reach.

The issue opens with the grid. Leaders from the transmission, generation and distribution segments of the sector discuss the practical realities of balancing sun and wind: maintaining voltage and frequency stability, managing intermittency, and building a smarter, more resilient network.

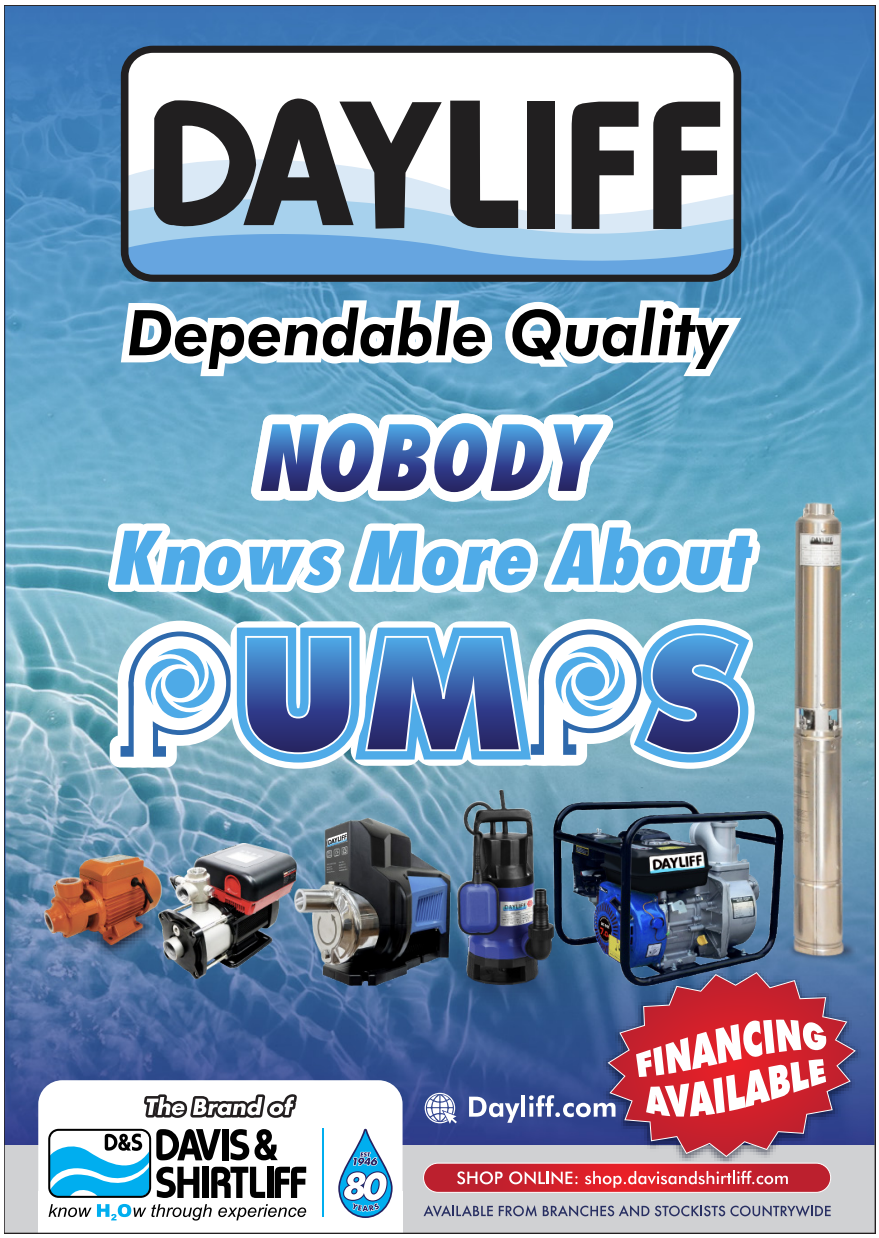
strong thread in this edition is local capability. We hear from industry and research institutions on local battery manufacturing, locally developed renewable-energy technologies, biomass and clean-energy research, and the skills pipeline that universities are building for the energy economy. These pieces make the case that Kenya can move from importer to innovator. Our members also contribute articles on the fundamentals of the energy transition, on rethinking energy storage, and on the engineering, safety and market risks posed by counterfeit solar and storage products, a reminder that standards and professional vigilance protect both people and investment. Technical papers from the AJERI Scientific Conference 2026 round out the

edition with current research on solar-powered smart systems, load forecasting and reliability, and composite materials from industrial waste.

I thank the writers, interviewees, contributing members and the Editorial Board, whose work made this issue possible within a demanding timeline. I also thank our readers, whose engagement keeps this publication relevant to the profession.

Our aim in this edition is to inform and to provoke action. Kenya's energy transition will be built by engineers, and I hope these pages inspire you to take part in it.

Happy reading.



Message From the President



Eng. Harrison Kiplimo Keter, PE, MIEK
President, Institution of Engineers of Kenya

It gives me great pleasure to welcome you to this edition of **Engineering in Kenya** Magazine, dedicated to theme, "**Renewable Energy & Energy Storage Engineering.**" This edition addresses the critical issues facing Kenya's energy sector with significance transformation, driven by the increasing adoption of renewable energy technologies, the need for greater grid resilience, the expansion of energy access and the emergence of energy storage as an important component of modern energy systems.

Energy is fundamental to economic and social development. As Kenya continues to pursue industrialization, digitalization, sustainable agriculture, manufacturing and improved access to essential services, the demand for reliable, affordable and sustainable energy will continue to grow. Meeting this demand requires not only investment in infrastructure, but also strong engineering expertise, innovation, appropriate regulation and effective collaboration among the various stakeholders in the energy ecosystem.

This edition provides a valuable platform for examining these issues through the experiences and perspectives of leading professionals, institutions and industry players. The content of this publication brings together voices from across the energy value chain, including whom share their perspectives and provides an opportunity to understand the technical, regulatory, operational and investment considerations shaping Kenya's energy future.

The discussion on grid stability and the integration of variable renewable energy is particularly important as Kenya continues to expand renewable generation. This edition provides valuable insights into the practical challenges associated with intermittency, demand management, voltage and frequency stability, and the integration of wind and solar resources into the electricity system.

Kenya needs to strengthen its grid infrastructure, invest in modern grid management technologies, expand energy storage solutions and enhance system flexibility to effectively accommodate increasing shares of variable renewable energy.

By addressing these challenges through coordinated planning, innovation and strategic investment, Kenya can not only strengthen the reliability and resilience of its own electricity system but also serve as an example to other African countries pursuing sustainable energy transitions. These engineering challenges require collaboration across the energy value chain, bringing together government, utilities, regulators, engineers, researchers and industry partners to develop practical and locally relevant solutions.

Equally important is the development of energy storage solutions. Batteries, mini-grids and other storage technologies have the potential to strengthen energy resilience and expand access, particularly in areas where conventional grid infrastructure remains challenging. Batteries, mini-grids and rural electrification, together with the discussion on Kenya's clean energy and energy storage roadmap, provides an opportunity to examine how technology and policy can work together to advance inclusive energy access.

This edition also highlights the importance of developing local capacity and industrial capability. Our local battery manufacturing, locally manufactured renewable-energy technologies and the development of Kenya's renewable-energy industry demonstrate the opportunities available to strengthen local value chains. The transition should create opportunities for Kenyan engineers, researchers, manufacturers, entrepreneurs and technical professionals to participate not only as users of imported technologies, but increasingly as innovators, designers, manufacturers and solution providers.

Research and education will be equally important. Research institutions and universities can make great shifts towards developing the knowledge and skills required for the energy transition.

Trough IEK council, we recognize that achieving a sustainable energy future requires collaboration. IEK is well positioned to bring together government, regulators, industry, academia, research institutions, development partners and the engineering profession. Through such partnerships, we can facilitate technical dialogue, support professional development, promote research and innovation, strengthen industry academia linkages and provide a platform through which engineering expertise can inform national development priorities.

I therefore encourage our industry partners to work closely with IEK in

creating opportunities for knowledge exchange, technical training, mentorship, research collaboration and exposure to emerging technologies. The energy transition requires practical solutions, and these are best developed when the expertise of industry is connected with the research capabilities of academia, the professional knowledge of engineers and the policy direction of government.

I am very pleased to note that this edition attracted diverse contributors of our members with most of them in the engineering practice. I encourage members and readers to enjoy these features, engage critically with the ideas presented and consider how the lessons and opportunities highlighted can be translated into practical engineering solutions.

As the engineering profession continues to evolve, we must remain committed to lifelong learning, innovation, ethical practice and collaboration. Renewable energy and energy storage will create new areas of engineering practice and professional opportunity, particularly for young and emerging engineers. I encourage our members to embrace these opportunities and equip themselves with the knowledge and competencies required to contribute meaningfully to Kenya's energy future.

I commend the Editorial Board, contributors, interviewees, industry partners and all those who have supported the development of this edition. Their collective contribution reflects the importance of professional knowledge sharing in advancing engineering practice.

I invite you to read, reflect, share and engage with the content presented in this edition. More importantly, I encourage us to continue building partnerships that transform engineering knowledge and innovation into solutions that improve lives, strengthen industry and support Kenya's sustainable development.

I wish you an enjoyable, informative and inspiring reading experience as you explore the diverse perspectives, innovations and engineering solutions featured in this edition.

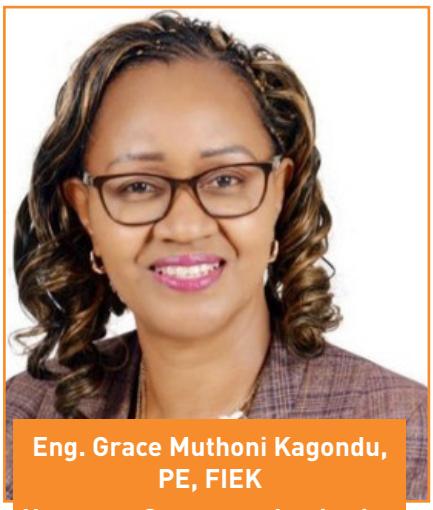
> I also encourage you to take the conversation beyond these pages by joining the Institution of Engineers of Kenya (IEK) for the 33rd IEK International Convention, scheduled for 24th –27th November, 2026 in Mombasa, Kenya, under the theme ***"Intelligent Systems for Accelerated and Sustainable Growth."***

The Convention will provide an important platform for engineers, researchers, industry leaders, policymakers and other stakeholders to exchange knowledge, showcase innovations and deliberate on emerging technologies and solutions that can accelerate Kenya's sustainable development. As the country advances its energy transition and embraces intelligent systems, such platforms are essential for strengthening collaboration between the engineering profession, industry, academia and government.

I therefore invite IEK members, engineering professionals, students, industry partners and all our readers to participate actively in the Convention. Your engagement will contribute to the exchange of ideas, partnerships and practical solutions that can shape the future of engineering and support Kenya's journey towards a resilient, sustainable and technologically advanced economy.

We look forward to welcoming you to Mombasa for this important gathering and to continuing the conversation on how engineering can drive intelligent, inclusive and sustainable growth.

Message From the Honorary Secretary



Eng. Grace Muthoni Kagondu, PE, FIEK

Honorary Secretary, Institution of Engineers of Kenya

It is my pleasure to welcome you to EiK issue 29, under the theme *"Renewable Energy & Energy Storage Engineering."* This edition provides an opportunity to reflect on one of the most important areas shaping the future of engineering, industry and national development.

Kenya has made significant progress in the adoption of renewable energy, while continuing to explore innovative approaches to improve energy reliability, accessibility and sustainability. As these developments accelerate, the engineering profession has an important responsibility to ensure that technological advancement is supported by sound engineering practice, research, innovation and continuous professional development.

The transition to cleaner and more resilient energy systems is creating new areas of professional practice. Engineers are increasingly required to understand not only conventional energy systems, but also renewable energy technologies, energy storage, smart grids, digital systems, energy efficiency and emerging approaches to managing increasingly complex energy networks. This changing environment presents opportunities for engineers to expand their competencies and contribute to solutions that respond to Kenya's evolving needs.

The content presented in this edition reflects the breadth of this transformation. It brings together perspectives and experiences from engineers, researchers, industry practitioners and other stakeholders working across different areas of the energy sector. The discussions provide an opportunity for readers to gain practical insights into renewable energy development, grid stability, energy storage, rural electrification, local manufacturing and the development of Kenya's clean energy industry.

I am particularly pleased to see the contribution of IEK members and engineering practitioners to this edition. Professional knowledge becomes more valuable when it is shared, discussed and applied. Platforms such as Engineering in Kenya Magazine therefore play an important role in documenting engineering experiences, encouraging professional dialogue and exposing members to developments taking place across different sectors.

For young and emerging engineers, the changing energy landscape offers considerable opportunities for learning, innovation and career development. I encourage our members to remain curious, pursue continuous professional development and actively engage with industry, academia and fellow professionals. Building the competencies required for emerging technologies will enable engineers to participate meaningfully in Kenya's energy transition and in the wider transformation of the economy.

The IEK remains committed to strengthening opportunities for professional interaction, technical learning and knowledge exchange. Our engagement with industry, government institutions, universities, research organizations and development partners is essential in creating an environment where engineering knowledge can translate into practical solutions. Through these partnerships, IEK can continue to promote innovation, mentorship, research collaboration and professional excellence.

I commend the Editorial Board for its continued commitment to providing a platform for engineering knowledge and professional discourse. I also appreciate all contributors, reviewers, interviewees, industry partners and members whose efforts have made this edition possible. Their collective contribution demonstrates the value of collaboration in advancing the engineering profession.

I encourage our readers to explore the diverse features in this edition, reflect on the opportunities presented and share the knowledge gained with colleagues and peers. The conversations initiated through this publication should extend beyond its pages and encourage further engagement within the engineering community.

As we look ahead, I invite you to participate in the 33rd IEK International Convention, scheduled for 24th–27th November 2026 in Mombasa, Kenya, under the theme "Intelligent Systems for Accelerated and Sustainable Growth." The Convention will provide an important platform for engineers, researchers, students, industry leaders, policymakers and other stakeholders to exchange knowledge, showcase innovations and explore emerging technologies that can contribute to sustainable development.

I encourage IEK members and all our readers to take advantage of this opportunity to network, learn and contribute to the conversations shaping the future of engineering.

I wish you an enjoyable, informative and inspiring reading experience and look forward to your continued engagement with the Institution of Engineers of Kenya.



Powering Africa's Future: Engineering Clean Energy, Manufacturing, and Local Innovation

By Dalmus Mbai, CEO, Safer Power Ltd

> **Africa is blessed with some of the longest peak sun hours in the world, averaging roughly 5 to 5.5 hours of intense sunlight daily.**

When we talk about Africa and engineering in the same space, we are looking at a landscape rich with potential, yet defined by stark challenges. Across the continent, most of our developmental bottlenecks are fundamentally power-related. If we look at industrial manufacturing, we find that factories cannot scale or operate efficiently because of unreliable grid infrastructure. If we look at healthcare or education, remote institutions struggle to provide quality services simply due to a lack of dependable power connectivity.

Yet, when we look at renewable energy, the narrative shifts entirely. Africa is blessed with some of the longest peak sun hours in the world, averaging roughly 5 to 5.5 hours of intense sunlight daily. For years, however, we have barely scratched the surface of that potential.

My own journey into this sector did not start in corporate boardrooms. Back when I was studying electrical engineering at the University of Nairobi alongside my co-founder Eng. Fidelis Musau, student life was defined by financial strain and academic deferments, one year in, one year out, working odd jobs just to raise tuition fees. Our first business venture collapsed entirely between 2012 and 2015 due to unpaid county government debts. But we refused to give up. In 2016, we founded Safer Power Limited, initially as a small vehicle to help us navigate campus life and bridge the gap between classroom theory and practical engineering reality.

From those humble beginnings, Safer Power has grown from a small contracting firm into a fully registered regional entity with operations stretching into Tanzania, Burundi, and Botswana. That growth taught me a fundamental lesson: the energy deficits plaguing Africa should not be viewed merely as crises, they are immense business opportunities waiting for local engineers to solve.

Innovating Beyond Solar: Green Hydrogen, Storage, and Local Manufacturing

The renewable energy sector is evolving rapidly, and deploying traditional solar PV systems is only the first step. To build a truly resilient energy ecosystem, we must look at how power is managed, stored, and diversified.

One of the greatest milestones in recent years has been the dramatic drop in the cost of Battery Energy Storage Systems (BESS). Renewable energy sources like solar are inherently intermittent; clouds pass, weather shifts, and industrial plants require constant, reliable baseline power. Integrating advanced BESS solutions stabilizes these fluctuations, transforming solar installations from erratic power sources into dependable, 24-hour assets that can slash commercial and industrial power costs by up to 65%.

Beyond standard storage, the global energy transition is moving aggressively toward emerging frontiers like green hydrogen, green ammonia, and green fertilizers. Green hydrogen serves as an exceptional energy carrier, produced by using excess renewable energy to split water molecules into hydrogen and oxygen. By utilizing combined heat and power (CHP) systems, efficiency rates can climb past 85–90%, providing industrial and agricultural processing plants with both clean electricity and thermal energy.

Furthermore, we must address the environmental life-cycle of our technologies. Importing massive containers of lithium-ion batteries means we are simply importing tomorrow's electronic waste, waste that will eventually need to be disposed of in a region lacking recycling infrastructure. Green hydrogen and ammonia offer circular, zero-emission alternatives where water is the primary byproduct.

However, true industrial independence cannot be achieved if we remain a consumer market dependent entirely on imported knocked-down kits. Local assembly and manufacturing are vital. At Safer Power, while we source core components from original equipment manufacturers (OEMs), we manufacture roughly 40% to 50% of our balance of plant locally, including switchboards, control panels, and metal enclosures, right here in our Nairobi facility.



380kWp with 215kWh BESS at Quick Mart Nyali by Safer Power, Feb 2026

When we built the electrical control architecture and switchboards for landmark projects like the KAIST University campus in Konza, every single switchboard was custom-manufactured in-house. Local manufacturing cuts shipping costs, drives down consumer prices, creates dignified jobs for young technicians, and proves that East Africa can build engineering products that rival global standards.

Confronting Industry Realities: Policy, Culture, and Fair Competition

Expanding across East Africa has taught me that Kenyan engineers possess an incredible competitive edge. When operating within the East African Community (EAC), we quickly realize that Kenya's regulatory bodies, such as EPRA and NCA, and our rigorous academic training place our professionals' decades ahead of many regional peers.

However, we face steep hurdles that must be addressed candidly:

i. **The Policy-Practice Gap:** While regional frameworks promise free movement of goods, services, and labor, the reality on the ground often involves bureaucratic resistance designed to protect domestic markets from outside competition.

ii. **The Perception Trap:** There remains an entrenched colonial bias, both locally and regionally, that anything manufactured in Africa is inherently inferior to imports from Europe or Asia. Overcoming this requires relentless proof of superior quality.

iii. **Internal Cultural Challenges:** If the engineering fraternity is to rise, we must address internal integrity. Incidents of unethical practice severely compromise project timelines, damage corporate reputations, and destroy the promising careers of young engineers. Combined with socio-economic pressures like substance abuse, these habits prevent young professionals from transitioning to leadership.

iv. **Unfair Foreign Competition:** We see foreign contractors entering our market not just for mega-infrastructure, but flooding local retail and sub-contracting tiers, often bypassing work-permit regulations that mandate proving no local engineer can do the job. If we complain about youth unemployment while handing every local tender to foreign entities, we suffocate our own ecosystem.

Empowering the Next Generation of Problem Solvers

Drawing from most of my professional and social interactions, it is painfully clear that brilliant minds are being left behind simply due to a lack of incubation and mentorship. To young graduate engineers across Kenya, my message is simple: **Start small and, start now.** Do not wait for ideal employment conditions or massive capital injection.



Safer Power CEO, Dalmus Mbai, with the co-founder Eng. Fidelis Musau

Engineering companies are built on grit, technical precision, and trust. Seek out mentorship, partner with multi-disciplinary teams, and master the practical aspects of your trade. At Safer Power, we are actively seeking collaborating with the Institution of Engineers of Kenya (IEK) to establish a dedicated CSR fund and mentorship framework. Our vision includes supporting young innovators, offering hands-on subcontracting opportunities on our 100-megawatt pipeline, and sponsoring professional engineers for international certifications in emerging fields like green hydrogen in places like Pisa, Italy.

As we look toward the next decade, my Pan-African vision for Safer Power, and for Kenya's engineering sector at large, is clear. We must stop exporting raw materials only to import finished goods. We have the technical talent, the sunshine, the raw resources, and the drive. Engineering is not merely about designing two-bedroom houses or importing turnkey systems from abroad; it is about building the industrial backbone of our nations. If we commit to investing in local manufacturing, protecting our workforce, and mentoring our youth, Kenyan engineers will not just watch Africa's transformation from the sidelines, we will lead it.



Beyond Baseload: Integrating Nuclear Energy, Renewables and Storage for Kenya's Sustainable Energy Future

By Lois Kinya Thuranira,
Corporate Communication Officer,
Nuclear Power and Energy Agency (NuPEA)

ABSTRACT

Kenya has one of the world's lowest-carbon electricity systems. The Energy and Petroleum Regulatory Authority (EPRA) report for the year ended 30 June 2026 records renewables at 81.13% of electricity generation. Peak demand reached 2,514.28 MW, an 8.55% increase, while electricity generation rose 8.44% to 15,692.81 GWh. The report also highlights rising evening demand, 392.36 GWh of geothermal steam vented overnight, and electricity imports accounting for 12.19% of supply. Drawing on these findings and the International Atomic Energy Agency's (IAEA) framework for nuclear–renewable hybrid systems, this article examines how coordinated nuclear power, renewables and storage could strengthen reliability and support industrialization. It assesses the economic and sustainability implications and outlines practical recommendations for engineers and policymakers.

Introduction: From Electricity Generation to Energy-System Integration

Energy transitions are often described in terms of individual technologies: solar panels, wind turbines, geothermal plants, batteries or nuclear reactors. However, a reliable power system depends on how these resources work together. Electricity must be generated, transmitted, balanced and delivered in real time while maintaining frequency and voltage stability and keeping costs manageable. Storage can shift energy across time but does not create it; nuclear power generates electricity but is not a storage technology. These distinctions matter when a system is planned for long-term growth.

For Kenya, the question is how to build on a strong renewable base while meeting rising demand, strengthening energy security and supporting industrialization. The answer is not a competition between nuclear and renewables, instead, it is a careful assessment of the combination of resources, networks, storage and operating practices that serves the country best, hour by hour as well as year by year.

Kenya's System in 2025/26: A Clean Grid with a Shape Problem

EPRA reports that renewable sources supplied 81.13% of electrical energy in 2025/26, up from 80.48% the year before. Geothermal contributed 40.91%, hydro 22.65%, wind 12.31% and

utility-scale solar 3.0%. The grid emission factor is estimated at 0.053 tCO_2/MWh, which is very low by international standards.

However, this clean energy profile is accompanied by growing demand and persistent system constraints. Electricity generation increased by 8.44% to 15,692.81 GWh, while peak demand reached 2,514.28 MW on 29 June 2026. Imports accounted for 12.19% of electricity supplied, totaling 1,913.66 GWh, of which 82.45% originated from Ethiopia. This represented an increase from 10.60% in the previous year, while interconnected thermal plants contributed a further 8.34%. Reliability also remains a concern: EPRA's five-year review found that the System Average Interruption Duration Index (SAIDI), which measures the average duration of electricity interruptions per customer, remained above the regulatory threshold. These trends underscore the need to strengthen not only generation capacity, but also storage, grid flexibility and overall system reliability.

Table 1. Selected indicators (source: EPRA)

Indicator	2024/25	2025/26
Peak demand (MW)	2,316.22	2,514.28
Generation (GWh)	about 14,472	15,692.81
Renewable share of energy	80.48%	81.13%
Imports, share of energy	10.60%	12.19%
Curtailment (GWh)	668.70	403.94

How Nuclear and Renewables Fit Together

The International Atomic Energy Agency (IAEA) classifies nuclear–renewable hybrid systems from loosely coupled (generators coordinated through the grid) to tightly coupled designs that share heat, hydrogen or water production, and notes that no tightly coupled system yet exists.

Kenya's practical path is loosely coupled: renewables supply most energy, nuclear provides a stable round-the-clock layer, and batteries and flexible hydro shape the output (illustrated in Figures 1 and 2). Modern reactors can load-follow, with designs specified for 50–100% output and ramp rates of 3–5% per minute, but the IAEA stresses that high-capital plants earn most at high capacity factors. Therefore, surplus should be directed to storage, new demand or hydrogen rather than throttling plant.

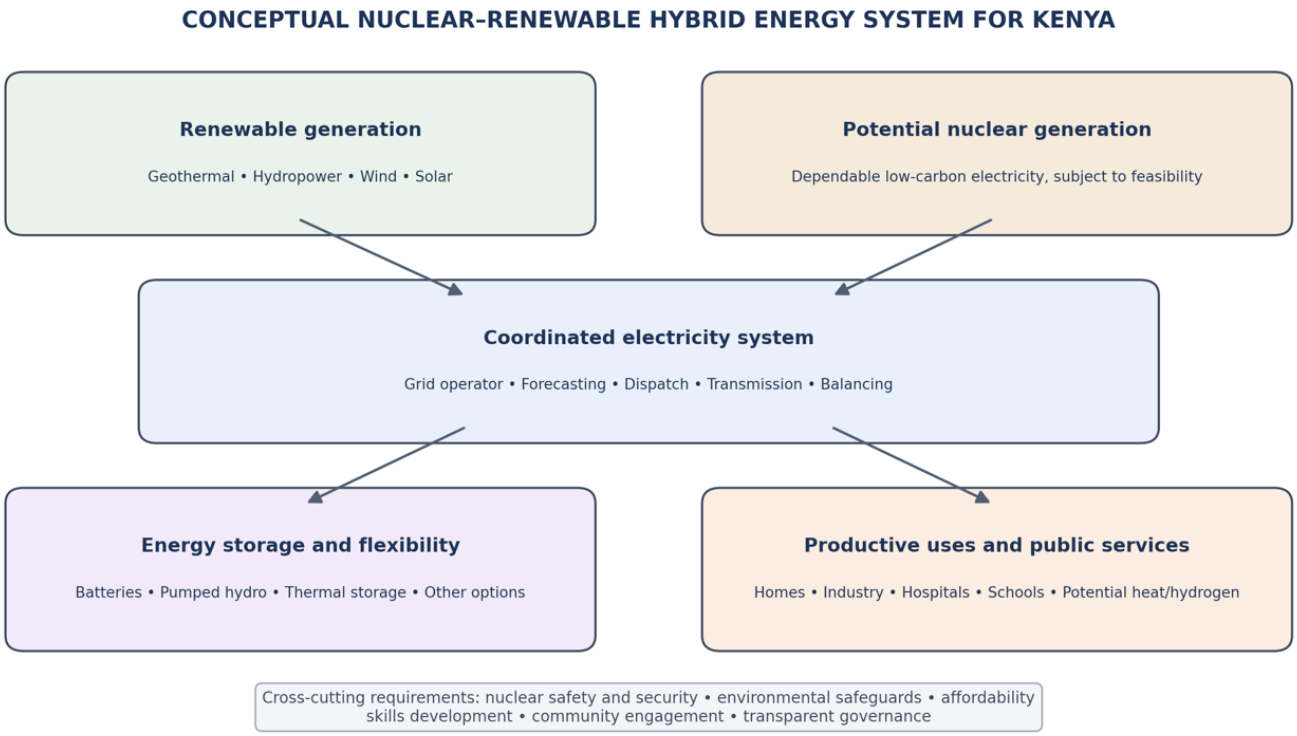


Figure 1. Conceptual nuclear–renewable system for Kenya (illustrative, not a final technology mix).

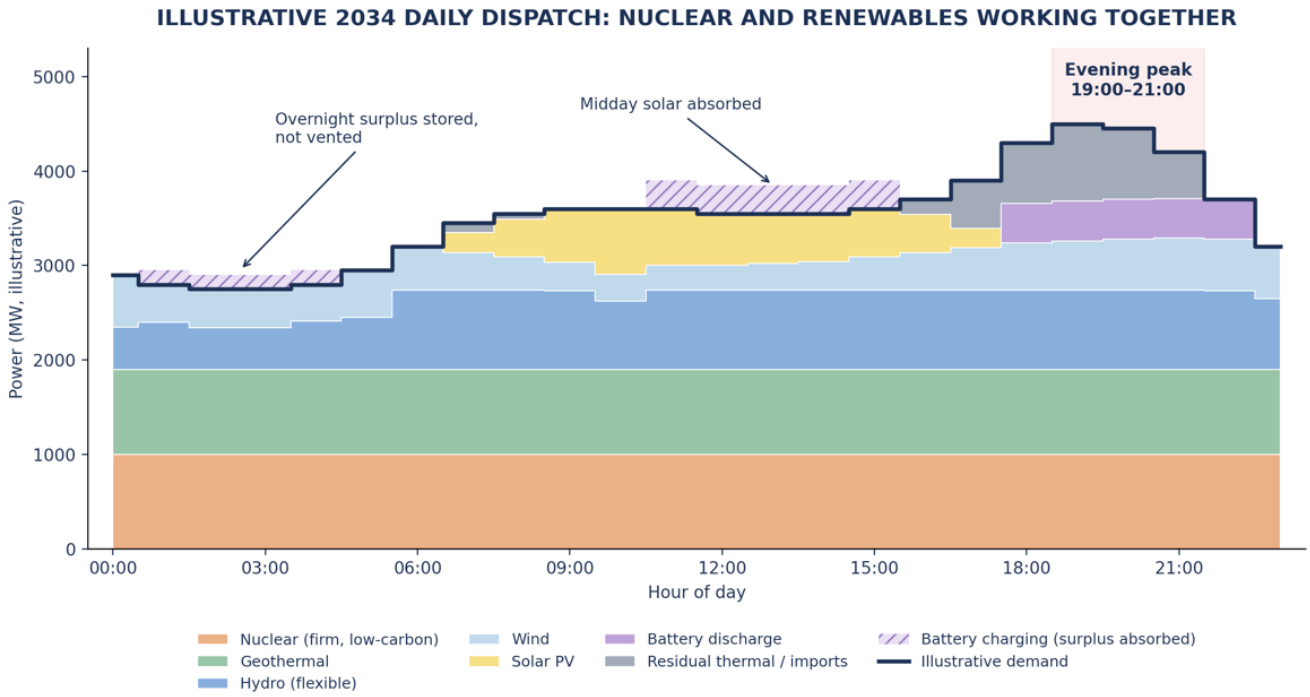


Figure 2. Illustrative 2034 dispatch: nuclear gives firm output, batteries absorb surplus and cover part of the evening peak, hydro flexes; the grey residual shows storage and transmission must scale with demand.

The Power of Nuclear to Kenya's Energy Generation

The Nuclear Power programme is now concrete. Nuclear Power and Energy Agency coordinate the development of the 19 nuclear infrastructure issues, KenGen will own and operate the plant and the Kenya Nuclear Regulatory Authority will license it. Lenya, in Siaya County, is the preferred site, with groundbreaking targeted for March 2027, commissioning for 2034 and a cost of about Sh500 billion. The stated capacity ranges from an initial 1,000 MW to 2,000 MW, both are treated as scenarios.

At the global fleet's 83% average capacity factor, 1,000 MW would generate about 7,300 GWh a year, 46% of 2025/26 generation and more than twice the roughly 3,200 GWh now met by imports and thermal plants; meaning a 2,000 MW would generate about 14,600 GWh, 93% of it. Demand growth will absorb much of this, which is precisely the point: firm domestic supply that keeps pace with an economy growing at 8% a year, without deepening dependence on imports or fuel-price shocks.

Transformative Potential: Growth and Sustainable Development

Nuclear power's value to Kenya lies in a set of properties that map directly onto development goals (Table 2).

Lenya, in Siaya County, is the preferred site, with groundbreaking targeted for March 2027, commissioning for 2034 and a cost of about Sh500 billion. The stated capacity ranges from an initial 1,000 MW to 2,000 MW, both are treated as scenarios.

Table 2. Nuclear properties and their development benefits

Property	Evidence	Development benefit
Firm, high-availability output	83% global average capacity factor	Reliable power for industry, rail and data centres; lower SAIDI
Very low emissions	5.1–6.4 gCO_2eq/kWh over the life cycle, lowest of 22 technologies	Keeps the 0.053 tCO_2/MWh grid clean as demand grows; supports the NDC's 35% abatement by 2035
Small land footprint	Lowest life-cycle land occupation studied]; less land than comparable hydro	Less displacement; land left for farming
Long asset life	NuPEA cites a life of up to about 100 years and payback in about 20	Decades of stable tariffs once debt is repaid
Jobs and skills	5,000–12,000 construction jobs; Sh36.7bn research reactor planned at Konza city	Engineering workforce, medical isotopes application, agricultural research, industrial testing

Development follows when reliable and affordable power meets demand: electrified industry and transport system, off-peak load rewarded by EPRA's time-of-use tariff, and, at a co-located site, heat for hydrogen or desalination. The same plant that secures supply, also anchors a skills base that no renewable project builds on its own.

Sustainability Beyond Engineering: People, Institutions and Development

With a grid emission factor of 0.053 tCO_2/MWh, the case for new firm capacity is less about decarbonising today's grid than reducing reliance on thermal generation (8.34%) and imports (12.19%), while supporting electrification of transport, cooking and industry. These efforts can contribute to Kenya's target of reducing emissions by 35% against business-as-usual levels by 2035 [1]. Nuclear is low-carbon, but not renewable, so its contribution should be assessed against emissions targets rather than renewable-energy targets alone.

Sustainable energy infrastructure must also earn public trust. Early stakeholder engagement, credible environmental and social assessments, transparent information, accessible grievance mechanisms and fair benefit-sharing help address impacts on land, livelihoods and local services. Employment and skills commitments should be realistic and linked to workforce and procurement plans.

Ultimately, sustainability means delivering reliable energy while strengthening public accountability, supporting inclusive development and protecting vulnerable communities and future generations.

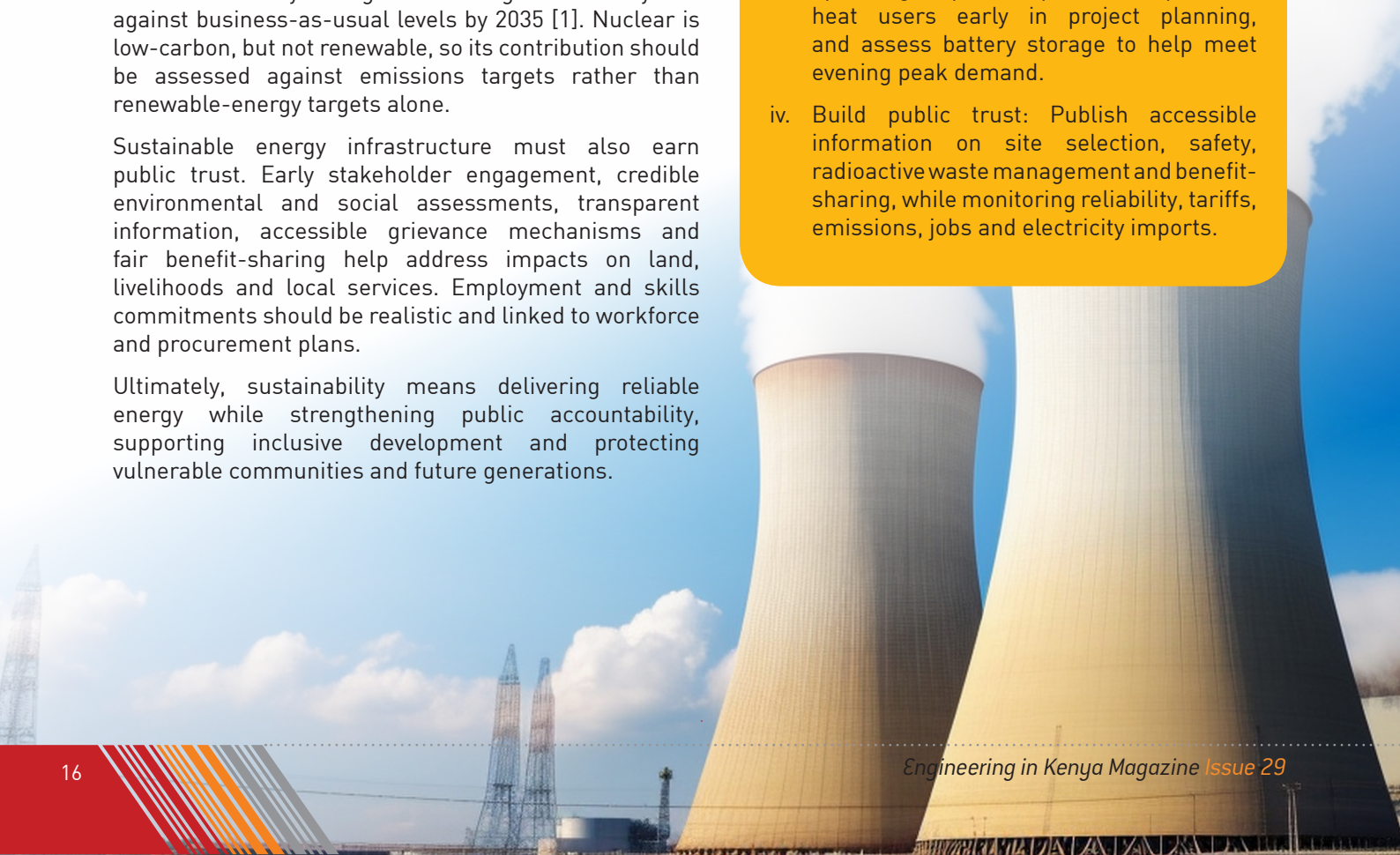
Recommendations;

i. Model first: Use 8,760-hour dispatch models to compare nuclear, renewables, storage and grid investments based on total system costs and reliability.

ii. Grow flexible demand: Promote time-of-use pricing, electric mobility, industrial electrification and pilot hydrogen production to make productive use of surplus electricity.

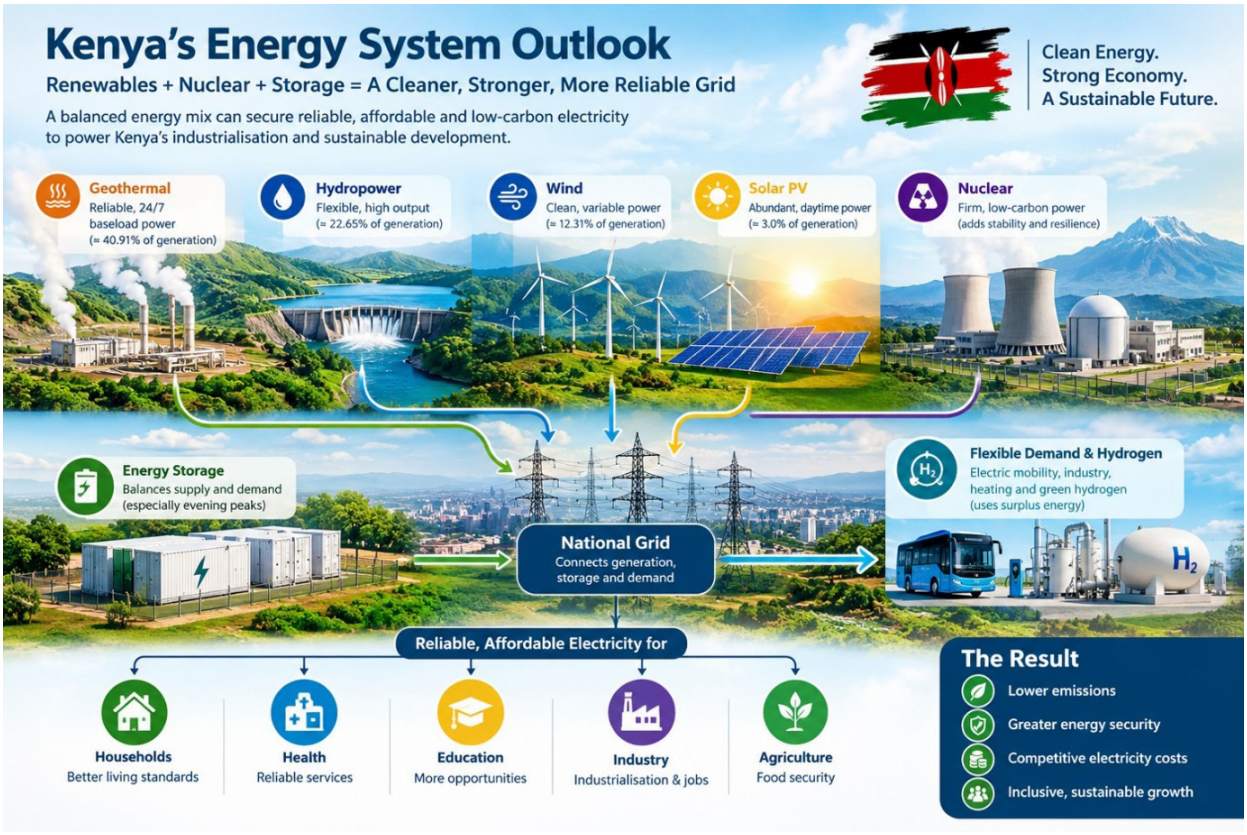
iii. Plan for flexibility: Specify minimum operating output, ramp rates and potential heat users early in project planning, and assess battery storage to help meet evening peak demand.

iv. Build public trust: Publish accessible information on site selection, safety, radioactive waste management and benefit-sharing, while monitoring reliability, tariffs, emissions, jobs and electricity imports.



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Kenya's Integrated Energy Mix: Powering a Cleaner, Stronger and More Reliable Future



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Engineering Education, Applied Research and Technical Skills: Interview Insights from the Technical University of Kenya (TUK)

Bio Data: Dr. Eng. Mutua is a senior lecturer and Chairman of the Department of Mechanical and Aerospace Engineering at the Technical University of Kenya. He holds a Doctor of Engineering (D.Eng.) degree in Materials Processing Engineering from the Centre for Civil Aviation Composites (CCAC), Donghua University, China. He received his Bachelor of Technology Degree and Masters of Engineering (M.Eng.) from Moi and Donghua Universities, respectively.

His research interests include; green materials, composite materials, renewable energy, sustainability, circularity, Data Mining and use of bio-based resources to advance science while solving societal challenges.

He has published over 35 papers in peer reviewed journals, presented several papers in international conferences and registered some patents. He has also participated in several trainings locally and abroad and has work experience in both industry and academia. He is a Professional Engineer (PE) registered with Engineers Board of Kenya (EBK) and is a corporate member of the Institute of Engineers of Kenya (IEK).

Introduction: Preparing Engineers for the Renewable Energy Economy

Engineering education is undergoing significant transformation as countries increasingly embrace renewable energy, energy storage and digital technologies. In Kenya, this transition presents opportunities for engineers to develop innovative solutions, strengthen local industries and contribute to sustainable economic development. Eng. Dr. Fredrick N. Mutua, Chairperson of the Department of Mechanical and Aerospace Engineering at the Technical University of Kenya (TUK), argues that preparing graduates for this emerging economy requires a fundamental shift towards competency-based, practical and interdisciplinary engineering education.

Transforming Engineering Education for Emerging Energy Technologies

According to Dr. Mutua, engineering programmes must move beyond content-centered teaching towards learning that equips graduates with demonstrable technical competencies. Projects such as Lake Turkana Wind Power and the Garissa Solar Power Plant illustrate the multidisciplinary nature of

renewable-energy engineering and the need for graduates who can apply their knowledge to real-world challenges. Universities should therefore strengthen capstone projects addressing industry problems, introduce laboratory exposure early in training and adopt outcome-based assessment methods that measure practical competence.

Digitalization must also become an integral part of engineering education, with students acquiring proficiency in modelling tools, Python programming, Supervisory Control and Data Acquisition (SCADA) systems and data analytics for energy storage, hybrid power systems and electric mobility. Equally important is lifelong learning through short courses, micro-credentials and professional certificates in solar photovoltaic systems, energy storage, grid codes and safety standards, enabling engineers to maintain their competence throughout their careers.

Essential Technical and Practical Competencies for Engineering Graduates

To remain relevant as Kenya expands its use of renewable energy and energy-storage technologies, engineering students must first master the fundamentals of mathematics, physics, thermodynamics, electrical machines, power electronics, materials and control systems. These foundational disciplines provide the basis for understanding and developing technologies across the energy sector.

Students should complement them with practical knowledge of solar photovoltaic, wind and small-hydropower systems, battery technologies, battery management, safety and degradation analysis. They must also understand power-system integration, including grid codes, protection systems, power quality, inverter stability and SCADA. Digital competencies in the Internet of Things (IoT), instrumentation, Python and MATLAB are increasingly indispensable.

Practical training should extend to fabrication, wiring compliant with International Electrotechnical Commission (IEC) standards, commissioning and occupational safety. Beyond technical knowledge, graduates need project management, communication, procurement, and entrepreneurship skills to translate engineering solutions into viable projects and businesses.

Strengthening Laboratory Based and Industry Oriented Training

Achieving these competencies requires universities to move beyond predominantly theoretical instruction and invest in laboratory-based, industry-oriented training. Dr. Mutua recommends developing industry-relevant facilities for solar photovoltaic systems, wind energy, battery testing and grid simulation, while encouraging institutions with limited resources to share facilities.

At TUK, renewable-energy research provides a foundation for strengthening practical training. Project-based learning should challenge students to address authentic engineering problems, including mini-grid optimization and battery thermal management. Partnerships with industry can further enhance learning through internships, industrial attachments, guest lectures and jointly supervised projects.

Remote laboratories, digital twins and virtual commissioning can expand access to practical learning environments, allowing students to become familiar with industrial standards, operational requirements and safety procedures before entering employment.

Developing Locally Relevant Renewable-Energy Technologies

Dr. Mutua emphasizes that African universities must become producers of locally relevant technologies rather than merely adapting solutions developed elsewhere. Kenya and other African countries face distinctive environmental and socioeconomic conditions, including high temperatures, dust, arid climates and dispersed rural energy demand. These conditions create specific engineering challenges that imported technologies may not adequately address.

Universities should therefore priorities research into photovoltaic cooling, dust mitigation, battery thermal management, solar-powered cold chains and mini-grid control systems. Collaboration with Kenyan industry can support the development of locally manufacturable components, battery-pack assembly and renewable-energy systems, increase domestic value addition and create employment.

Universities should additionally provide independent testing,



To remain relevant as Kenya expands its use of renewable energy and energy-storage technologies, engineering students must first master the **fundamentals of mathematics, physics, thermodynamics, electrical machines, power electronics, materials and control systems.**

performance validation and standards support in collaboration with institutions such as the Kenya Bureau of Standards (KEBS). Such efforts would strengthen the relationship between research, industrial development and public policy while enabling locally developed technologies to respond more effectively to Kenya's needs.

Bridging the Gap Between University Research and Industry Needs

Despite the growing importance of university research, significant gaps remain between academic outputs and the needs of industry, government and society. Dr. Mutua identifies research disconnected from national priorities, inadequate applied-research funding, weak university–industry collaboration, duplication of research efforts, limited data sharing and the failure of many research outputs to progress beyond academic publications as major obstacles.

He argues that research agendas should align more closely with national development priorities, including Kenya Vision 2030, the Least Cost Power Development Plan (LCPDP) and county energy plans. Universities should also recognize and reward prototypes, patents, policy contributions, and commercialization alongside scholarly publications.

Institutionalized partnerships, joint laboratories, industry co-funded projects, skilled technical support, policy briefs and demonstration forums can help bridge the gap between research and implementation. Ultimately, research success should be measured not only by publications but also by the practical solutions delivered to Kenya's engineering, economic and societal challenges.

Integrating Multidisciplinary Skills into Engineering Curricula

The multidisciplinary nature of renewable energy demands a corresponding transformation of engineering curricula. Modern energy systems integrate generation, storage, power electronics, controls, communication and consumption, making it increasingly difficult to address emerging challenges within isolated academic departments.

Dr. Mutua advocates an integrated approach that combines electrical, mechanical, thermal and data-science competencies. Students should undertake projects such as designing solar–wind–battery mini-grids, incorporating system sizing, protection, communication and economic modelling. Programming, simulation, SCADA, IoT and data analytics should be embedded throughout engineering programmes rather than treated as peripheral subjects.

Students also need an understanding of grid codes, technical standards, energy markets and policy frameworks. Cross-departmental teaching and collaborative projects can produce what Dr. Mutua describes as T-shaped engineers: professionals with deep expertise in a particular discipline and broad competence across interconnected engineering systems.

Career Opportunities for Kenyan Engineers in Renewable Energy

Kenya's substantial renewable-energy resources offer engineers opportunities throughout the development, deployment, operation and maintenance of energy infrastructure. In geothermal energy, opportunities include drilling, plant operations, corrosion management and direct-use applications. Solar energy supports employment in utility-scale installations, rooftop systems, mini-grids, irrigation and cold storage. Wind energy creates opportunities in site assessment, installation, grid integration and predictive maintenance.

Meanwhile, the expansion of energy storage and transmission infrastructure is increasing demand for expertise in batteries, controls and power systems. Engineers can also contribute through energy auditing, testing, certification, climate finance and policy advisory services. Entrepreneurship in installation, maintenance and component manufacturing offers additional opportunities to generate employment, strengthen domestic industry and support the country's energy transition.

Prioritizing Energy-Storage Research and Innovation

As renewable-energy penetration increases, energy storage is becoming a critical component of reliable and resilient energy systems. Dr. Mutua recommends that Kenyan universities prioritize battery-pack design, local assembly, second-life batteries, thermal management and degradation modelling under Kenya's hot climatic conditions. Research should also examine battery storage for mini-grids, hybrid power systems and productive rural enterprises.

Complementary technologies, including pumped hydropower, thermal energy storage and agricultural cold chains, deserve attention because of their potential to improve energy utilization and reduce losses. Kenya's solar and geothermal resources also provide a basis for developing expertise in green hydrogen, ammonia and long-duration energy storage.

Across these research areas, techno-economic modelling, recycling, safety standards and grid integration should remain central considerations. Partnerships with utilities and industry would help ensure that research addresses practical challenges while strengthening local manufacturing, maintenance and technical capacity.

Career Journey and Current Research Interests

Dr. Mutua's own career reflects the relationship between academic research, materials innovation and engineering practice. His career spans more than fifteen years in academia, research and industry collaboration across Kenya, Ethiopia, China and international settings. As Chairperson of the Department of Mechanical and Aerospace Engineering at TUK, he provides leadership in curriculum development, research and institutional partnerships.

His research interests include green

and composite materials, biodegradable polyamides, bio-briquettes produced from banana waste and electric-vehicle battery performance under Kenyan conditions. His current focus encompasses renewable-energy materials, energy-storage systems, sustainability and recycling, alongside efforts to strengthen laboratory capacity and industry collaboration.

Through this work, he seeks to advance locally relevant engineering solutions that support Kenya's transition towards cleaner and more sustainable energy systems.

Strengthening University–Industry Partnerships

Stronger university–industry partnerships are essential to translating these ambitions into practical outcomes. Such partnerships allow students to acquire workplace experience through internships, industrial attachments, industry-based projects and guest lectures. Companies, in turn, benefit from access to university laboratories, applied research, technical expertise, innovation and tailored staff training.

Dr. Mutua recommends structured arrangements incorporating framework agreements, shared laboratories, joint research programmes, clear intellectual-property arrangements and co-supervised student projects with measurable industrial outcomes. Government can reinforce these relationships through matching grants and research incentives.

Living laboratories, including campus energy systems and community mini-grids, can provide real-world environments in which students test their knowledge while companies evaluate and commercialize innovations. Properly designed partnerships therefore offer mutual benefits: they strengthen graduate employability, accelerate technology development and support Kenya's wider energy transition.

The Role of IEK in Advancing Engineering Practice

Professional institutions also have an important role in ensuring that engineering education, professional development and industry practice keep pace with technological change. The Institution of Engineers of Kenya (IEK), Dr. Mutua observes, can bridge academia, industry and regulatory bodies by advocating for curricula and accreditation frameworks that reflect emerging requirements in renewable energy, storage, grid integration and safety.

The institution can strengthen continuous professional development through practical courses, workshops and technical seminars while convening universities, industry stakeholders and regulators to identify skills gaps, establish research priorities and develop technical standards. Through ethical oversight, professional accountability and policy advocacy, IEK can help safeguard public safety while strengthening national engineering capacity.

Close collaboration among professional institutions, universities, industry and government will be essential to keeping engineering education and professional practice aligned with Kenya's changing energy landscape.

Advice to Aspiring Renewable Energy and Energy-Storage Engineers

For students aspiring to build careers in renewable energy and energy storage, Dr. Mutua's advice begins with mastering engineering fundamentals. Mathematics, physics, thermodynamics, electrical machines, control systems and materials remain indispensable, regardless of how rapidly technology evolves.

Students should develop practical competence in Python, simulation, data analysis and laboratory work, using internships, projects and competitions to complement classroom learning. They may specialize in battery storage, power electronics, grid integration, geothermal engineering or energy analytics while maintaining an understanding of the wider energy system.

Problem-solving, entrepreneurship, professionalism and a strong commitment to safety and ethical practice are equally important. Above all, graduates should focus on developing affordable, maintainable and context-appropriate solutions that respond to Kenya's needs. In Dr. Mutua's view, lifelong learning is fundamental to engineering success: obtaining a degree marks the beginning, rather than the end, of an engineer's education.



Beneath the Rift: The Engineering Powering Kenya's Geothermal Future



By David Nyaga
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The Heat Beneath the Fracture

The East African Rift System (EARS) is one of the most dynamic and tectonically active zones on the planet. As the Somali and Nubian plates slowly separate, the earth's crust thins, allowing the asthenosphere's magma to rise to remarkably shallow depths. This geological fracture heats subsurface rock formations and aquifers to extreme temperatures, often exceeding 300°C. For decades, this rugged terrain was primarily viewed as a topographical challenge for civil engineers. Today, however, it represents the bedrock of East Africa's clean energy transformation.

According to the Ministry of Energy, geological surveys estimate Kenya's untapped geothermal energy potential to be upwards of 10,000 megawatts (MW) distributed across more than 20 prospect areas mainly within the Kenya tertiary rift system. Harnessing this raw thermal energy has positioned Kenya as a global leader in renewable engineering. By extracting high-pressure steam trapped up to 3,000 meters below the surface, the nation has secured a steady, weather-independent, continuous baseload for its electricity grid, effectively decoupling economic growth from imported fossil fuels and drought-prone hydroelectric reservoirs.

Thermodynamic Realities and Reservoir Engineering

Geothermal electricity generation is fundamentally a high-stakes thermodynamic endeavor. Superheated fluids must be carefully extracted via directionally drilled wells, piped to surface-level separators where steam is flashed from the brine, and finally routed to massive turbines. Kenya's premier geothermal complex at Olkaria—nestled within Hell's Gate National Park represents nearly forty years of continuous iterative engineering.

At Olkaria, mechanical engineers utilize a sophisticated blend of single-flash and dual-flash condensing turbines. To maximize efficiency and ensure the longevity of the subterranean pressure systems, engineers employ binary cycle technology (such as the Organic Rankine Cycle). These binary plants recover residual heat from low-temperature geothermal brine (fluids too cool to flash into steam directly) by using it to vaporize a secondary working fluid with a lower boiling point. The spent, cooled brine is then aggressively re-injected deep into the reservoir to maintain hydrostatic pressure and guarantee resource sustainability for future generations.

The Decentralized Shift: Menengai and Modular Generation

While Olkaria relies on expansive, centralized infrastructure requiring miles of high-pressure steam gathering networks, the newer developments at the Menengai Caldera showcase a strategic shift toward decentralization. Here, the Geothermal Development Company (GDC) oversees the wellhead extraction, while Independent Power Producers (IPPs) are contracted to build modular power plants directly adjacent to the wells.

This modular wellhead approach offers significant engineering advantages. By utilizing smaller, 35 MW condensing turbines situated close to the extraction source, transmission heat losses along the steam lines are drastically minimized. Furthermore, this method curtails initial capital expenditure and slashes commissioning timelines, allowing grid-ready power to come online in phases rather than waiting for a massive, multi-year centralized build-out.

Table 1: Technical Profile and Capacity of Major Kenyan Geothermal Fields

Geothermal Field / Complex	Installed/Target Capacity	Primary Conversion Technology	Operational / Reservoir Strategy
Olkaria Field Complex (I–V)	~900 MW (Active)	Single/Dual-Flash & Binary Cycles	Deep re-injection wells; continuous centralized baseline supply.
Menengai Caldera Field	105 MW (Expanding)	Modular Condensing Turbines	Decentralized IPP model; reduced piping distance & thermal loss.
Eburru Geothermal Project	2.4 MW (Pilot)	Wellhead Condensing	Small-scale community generation; testing high-enthalpy shallow wells.
Paka & Silali (Baringo)	300 MW (Targeted)	High-Temperature Condensing	Greenfield frontier development; extensive exploratory drilling phase.

Source: Data synthesized from KenGen Annual Reports, Geothermal Development Company (GDC) projections, and African Development Bank Group (2025–2026).

The Storage Imperative and Grid Balancing

Despite its reliability, geothermal energy introduces unique rigidities into grid management. Geothermal power units are designed for constant, steady-state operation. Throttling geothermal wells or cycling multi-stage steam turbines up and down to match real-time consumer demand fluctuations is mechanically punishing. It induces severe thermal stress on turbine blades, accelerates mineral scaling in wellbores due to pressure drops, and inevitably leads to expensive energy venting.

This rigidity clashes with Kenya's rapid adoption of Variable Renewable Energy (VRE). With the integration of the 310 MW Lake Turkana Wind Power facility and vast utility-scale solar PV developments like the Garissa Solar Plant, the national grid is experiencing unprecedented volatility. Under International Energy Agency (IEA) classifications, Kenya has firmly entered Phase 3 of renewable integration—a stage where weather-dependent generation heavily dictates grid dispatch operations and directly threatens voltage stability. During peak sunlit hours, an influx of solar generation risks crowding out the grid, while sudden evening drops in solar output cause severe frequency dips as consumer demand spikes.

To navigate this bottleneck without reverting to expensive, fossil-fueled thermal peaking plants, control systems engineers are actively designing utility-scale Battery Energy Storage Systems (BESS). These advanced facilities, primarily utilizing Lithium Iron Phosphate (LFP) chemistry for safety and longevity, act as the grid's digital buffer. By providing sub-second frequency regulation, synthetic inertia, and vital peak-shaving capabilities, BESS installations absorb the excess solar energy during the day and seamlessly discharge it at night. This digital harmony preserves geothermal infrastructure as an uninterrupted baseload while stabilizing the national grid.

Table 2: Kenya's Installed Energy Matrix and Operational Grid Roles (2025/2026)

Power Generation Category	Estimated Capacity Share (%)	Grid System Function	Engineering & Operational Dynamics
Geothermal Energy	26 - 28%	Continuous Baseload	Operates near 100% capacity factor; rigid, non-variable steam drive.
Hydroelectric Power	23 - 25%	Baseload & Load Following	Highly flexible dispatch capabilities; highly vulnerable to seasonal drought cycles.
Wind & Solar PV (VRE)	23 - 25%	Variable / Intermittent	Weather-dependent generation; requires fast-acting grid support and frequency control.
Thermal & Battery Storage	24 - 26%	Peaking & Grid Stability	Thermal units transitioning to emergency standby; BESS absorbing VRE ramps.

Source: Data compiled from Energy and Petroleum Regulatory Authority (EPRA) reports and IEA Grid Integration Datasets.

Material Science and Smart Infrastructure Innovations

Harnessing subterranean steam is as much a materials science battle as it is a mechanical one. Deep-earth geothermal fluids are highly corrosive, containing aggressive concentrations of hydrogen sulfide (H2S), carbon dioxide (CO2), and dissolved silica. When this multiphase fluid reaches the surface turbines, mineral scaling and acid corrosion constantly threaten equipment integrity. To combat this, materials engineers integrate high-grade titanium alloy turbine blades and specialized austenitic stainless-steel piping (such as 316L grade). Automated chemical dosing systems are also deployed to continuously adjust fluid pH levels, thereby preventing the precipitation of silica scale inside the pipes.

Simultaneously, the civil and structural engineering disciplines are heavily integrating smart construction technologies. Leveraging advanced Building Information Modeling (BIM) and digital twin software, structural engineers can monitor plant assemblies and complex pipe geometries in real-time. By weaving Internet of Things (IoT) fiber-optic sensor arrays across the steam gathering mains and turbine housings, maintenance teams can detect thermal expansion strain, pressure drops, and structural micro-fractures instantly. This transition from blueprints to bytes ensures that geothermal plants consistently maintain availability factors well above 95%.

Engineering the Backbone of Sustainable Growth

According to the Engineers Board of Kenya, the country's 4,100 licensed engineers are actively building a grid that serves as the backbone for the nation's industrial aspirations. The success of the geothermal sector proves that robust energy leadership relies on sustained engineering excellence, visionary policy discipline, and rigorous material innovation. By tapping into the immense natural forces beneath the Rift Valley, Kenyan engineers have successfully decoupled the country's economic growth engine from expensive fossil fuel dependency.

As the nation marches toward total grid decarbonization, the synchronization of relentless geothermal baseload power with agile battery energy storage offers a resilient, world-class blueprint. It is a resounding testament that engineering brilliance, supported by the right policies, is the ultimate catalyst for sustainable development across the Global South.

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Engineering Circularity: Rethinking Biomass, Energy and Industrialization in Kenya

By Aarti Shah, CEO, Co-REGEN &

Robert Kibiwott, Project Developer, Compact Syngas Solutions, Co-REGEN

Kenya has made significant progress in generating renewable electricity through geothermal, hydro, wind and solar, and will finally be improving transmission. Yet challenges around reliability and affordability remain. Add to this the fact that industries such as Agri -processing require continuous heat, which today is often produced by burning fuelwood or fossil fuels, with the associated pollution.

Gasification is a thermochemical process which converts biomass in limited oxygen at around 700-1,000 degrees Celsius to a combustible syngas. This can then be converted to power and heat, and thermal energy can also be recovered from the gasifier. Gasification provides distributed renewable energy where biomass supply matches industrial energy demand. Its strength is not utility-scale generation, but its ability to locate energy production close to both the resource, and the user – industrial applications that require heat below 200 degrees C, and up to several megawatts of power.

The residual products are biochar, which is a carbon-rich structural soil amendment that improves fertilizer use efficiency. It must be tested for safety before it is deployed in food systems. There is also a raw condensate, the potential for which is being explored.

At Co-REGEN, we focus on gasification in a closed loop by incorporating agricultural residues. Circularity begins with a simple principle: keeping resources in productive use for as long as possible. What is considered "waste" in one process can become an input into another.

Gasification is not new, but installing a plant alone will not make it successful – and Kenya has already experienced failed projects. Through our partnership with Compact Syngas Solutions, we have learnt many lessons on how to move from a technology that has benefited from many years of research and development to a commercially viable solution for agricultural producers.

We started with a feasibility study assessing different biomass sources and developed a financial, environmental and social model. When we presented the results to the Kenyan tea sector at the beginning of 2024, the response was understandable: gasification looked promising on paper, but the sector wanted to see it working.

Hence our UNIDO Accelerate-to Demonstrate Facility (A2D) pilot funded by the UK government. As a lighthouse project, it will generate not only energy, but knowledge. We will understand actual plant performance, biomass supply, operational and maintenance requirements, and the changes required before the model can be replicated elsewhere. As public funding is supporting the demonstration, the lessons will benefit the wider ecosystem of engineers, researchers, policymakers, investors and industry.

Let's break this down.

While Africa may appear to have abundant feedstock, long-term consistent availability of eligible biomass at the right price point is essential. Otherwise, the plant could experience lower performance or



stop altogether. Remote sensing is a start, but we still need the ground truth from agribusinesses, farmers and current biomass suppliers. We must understand its potential moisture content, size, density, consistency, cost, location and competitive uses. We require signed agreements with suppliers.

There is an expectation that biomass will generate revenue for the seller, but in fact the more it costs the gasification plant, the more expensive the power, heat, biochar and other gasification products.

Tea bushes are regularly pruned as part of good agricultural practices, and generally left in the field as mulch, to contribute organic matter and nutrients to the soil. However, there are also some greenhouse gas emissions.

So, we do not advocate removing all the material, but rather sustainably recovering a proportion. We retain enough – after shredding it – on the soil to support its agricultural function.

In our pilot, we are removing one third once the pruning's have dried on top of the bush, then chipping and transporting them to the gasification facility.

These will provide electricity and process heat for the tea factory, and biochar will be returned to the tea farm in a closed loop. In other words, tea pruning as a resource move through several stages of value creation.

For each tea catchment area, we need to understand when pruning takes place, how much will be available, how it can be collected and processed, how far it must travel and how much storage is required. Transport is important because moving biomass over long distances can quickly affect project economics.

The same principle applies to agricultural residues such as those from sugar, sisal and other value chains. To reiterate, each resource will be assessed according to its physical characteristics, competing uses, collection requirements, transportation and economics. Some residues may require chipping, densification (such as briquetting or pelletizing) or drying before they can be gasified, and these processes must be incorporated into the overall energy and financial model.

Gasification is generally better suited to continuous operations, with shutdowns planned around maintenance. This means the plant must be designed around not just a reliable feedstock supply, but also the operating profile of the industrial user.

When processing tea, energy demand is connected to green leaf availability and processing schedules. We therefore co-design the system with the factory. We check when electricity and heat are required, and ensure biomass can be supplied during those periods. The biomass catchment, storage and processing, the capacity of gasification plant, and the integration into the factory's power and heat infrastructure, and use of biochar, must be considered.

The residual materials require proper management.

In our pilot, we are collaborating with agricultural researchers on how to optimize biochar. Different biochar can behave differently depending on their production conditions and the soil and agricultural system in which they are applied.

We are exploring the other residual streams, including the condensate, and its potential conversion into products for agriculture or other industrial processes.

These opportunities reinforce the broader circularity question: how do we maximize the useful value of the material entering the system and minimize what ultimately becomes a waste stream?

Next, we need to think beyond building the first plant. A technology cannot become an industry if every project has to start again from zero.

Local engineering will be central to that transition. A gasification plant requires chemical, electrical, mechanical and process engineering skills, together with biomass handling, conveyors, storage, instrumentation, controls and maintenance. Kenyan companies could specialize in different components and services. Local engineers also understand the climate, electrical systems, supply chains, and maintenance realities.

“These opportunities reinforce the broader circularity question: how do we maximize the useful value of the material entering the system and minimize what ultimately becomes a waste stream?

Over time, we would like to see more engineering, fabrication, research and after-sales support taking place within Kenya. Identifying where Kenya can realistically become competitive, and build capability accordingly, will require conversations with policymakers.

Sustained research and development will be essential. Examples of gasification technology developed or deployed in Kenyan institutions have stopped operating after the funding ended. If Kenya wants to become a developer and adapter of clean-energy technologies rather than simply an importer, there must be continued research, testing, learning, optimization, and adaptation.

The skills required are closer to us than we may realize. People who already run industrial boilers understand heat, biomass, safety and plant operations. With appropriate training, these skills can transition into gasification operations. There is also a significant opportunity to build a stronger pipeline of women, including technicians, operators, maintenance personnel, plant managers, fabricators and after-sales specialists. Engagement with TVET institutions can help connect training with the actual requirements of future plants.

For the value created by these systems to remain in Kenya wherever possible, we also need financing and policy.

Gasification requires patient capital because of the capital expenditure involved, and the time required to build and commission a plant, but it should lead to lower operating costs and greenhouse gas emissions, which is attractive for the factory, their clients and investors. Biomass collection, processing, transportation and storage also require investment.

We should not compromise technical standards simply to reduce initial capital costs; a cheaper system that is unreliable or expensive to maintain can ultimately cost more.

Policy must help create an environment in which renewable energy technologies become more affordable. This includes consideration of taxation on renewable energy equipment, spare parts and materials, as well as the wider cost of energy to industry. If Kenya wants to industrialize, electricity and heat should be viewed as utilities that enable productive economic activity.

The private sector has an important role. Tea companies need to co-design systems with technology developers and engineers around their energy requirements which, it is important to note, are evolving. They do not need to own the plant, but must invest time and technical knowledge in understanding and driving how it will work within their operations. Tea buyers could also consider investing in such solutions.

Wider adoption of gasification in Kenya today is dependent on proof. Industry wants to see continuous operation, reliable biomass supply, electricity and process heat generation and integration, and responsible management of residual materials under local conditions. It also wants to understand the economics and maintenance requirements.

Once our pilot plant is operating continuously in Kenya in 2027, we will build evidence of its performance, as well as the biomass supply chain and biochar impact. For 580-620 kg biomass per hour, we are expecting about 423 kW electricity and 600 kW thermal energy, and 15-19% biochar.

The conversation will then be about where plants should be located, their capacity, how biomass catchments should be organized, financing and the role of Kenyan engineering companies.

If we can take an agricultural residue, convert it into electricity and heat, recover valuable carbon-rich material, return some of that to the agricultural system, build local research capability and create employment for fabrication, operations, and maintenance and the supply chain, then we are doing more than generating energy.

We are building a circular industrial ecosystem.

That, for us, is the real opportunity presented by biomass gasification in Kenya.

“For 580-620 kg biomass per hour, we are expecting about 423 kW electricity and 600 kW thermal energy, and 15-19% biochar.





Renewable Energy and Storage Engineering in Kenya: Opportunities and Challenges

By Eng. Kimari M. Patrick

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Introduction

Renewable energy and storage engineering are important to improving energy efficiency and supporting sustainable industrial development in Kenya. The country's experience with hydropower provides a strong foundation for renewable energy development, while solar energy, biomass, cogeneration, and biogas present further opportunities. However, making effective use of these technologies requires more than identifying suitable energy sources. It also requires careful consideration of industrial energy demands, investment costs, local operating conditions, and the actual performance of installed systems.

Industrial energy consumption provides a useful perspective on these opportunities. Tea factories, for example, require substantial amounts of thermal energy and electricity to sustain their operations. Other manufacturing activities, including milk processing and juice production, also depend on thermal energy and the equipment needed to supply it. At the same time, growing interest in solar photovoltaic systems, energy monitoring technologies, and biogas demonstrates the range of applications available to engineers and energy entrepreneurs.



Despite this potential, several challenges continue to influence the adoption of renewable energy technologies. High initial capital costs can discourage investment, limited understanding of technological benefits can affect decision-making, and systems may perform differently in practice from what was anticipated during design. Energy storage presents additional financial and operational considerations, particularly for facilities that require electricity when solar generation is unavailable. Addressing these issues requires a

practical approach that connects engineering design with industrial requirements, financial realities, and local conditions.

Renewable Energy and Industrial Applications in Kenya

Kenya has considerable experience in hydropower, which has contributed significantly to the country's electricity supply. However, droughts experienced in the late 1990s highlighted the challenges associated with heavy reliance on this source. These experiences demonstrated the importance of considering alternative energy sources that could complement hydropower and provide greater diversity in the country's energy options.

Solar energy and biomass offer opportunities to address different energy requirements. Their importance is particularly evident in industrial applications, where the type of energy required depends on the processes being undertaken. While electricity is necessary for operating machinery and equipment, many industrial activities also require substantial amounts of heat. This makes thermal energy an important area for renewable energy development in Kenya.

In the tea industry, factories have traditionally relied on firewood and furnace oil to meet their thermal energy requirements. However, rising costs and environmental concerns have encouraged a gradual shift towards alternative energy solutions. Solar thermal energy and biomass present opportunities for meeting some industrial heating needs, although the suitability of each option depends on the requirements of the application.

Thermal energy is also relevant to other manufacturing activities, including milk processing and juice production. Such industries require equipment capable of supplying heat for different production processes. Boilers, dryers, and industrial cookstoves therefore remain important components of industrial energy use. Their continued demand presents an opportunity for Kenya to strengthen its capacity to design and manufacture energy equipment locally.

Despite the availability of engineering expertise in the country, Kenya continues to depend heavily on imported boilers and related equipment. Developing local manufacturing capabilities could help address this dependence while creating opportunities to apply local technical knowledge to practical industrial requirements. Strengthening domestic production of boilers, dryers, and industrial cookstoves would provide an opportunity for the country's engineering talent to contribute more directly to industrial energy solutions.

The development of local manufacturing is particularly relevant because industrial energy equipment must serve specific production requirements. Building domestic expertise in the design and manufacture of these systems would strengthen the country's ability to produce equipment for local applications rather than relying predominantly on imported alternatives.

Cogeneration and Energy Management in the Tea Industry

The tea industry provides an important example of the relationship between industrial energy requirements, technology selection, and investment decisions. Tea factories need both thermal energy for processing and electricity to operate machinery and other equipment. Meeting these two requirements makes cogeneration an important option to consider when assessing opportunities for improved energy utilization.

Cogeneration involves the simultaneous production of heat and electricity. Its relevance to tea factories lies in their demand for both forms of energy. By addressing these requirements through an integrated system, cogeneration offers the potential for long-term savings. It is therefore an important area of opportunity for improving energy management within the tea-processing industry.

> **The availability of a suitable technology does not automatically lead to its adoption**

However, the adoption of cogeneration faces a significant obstacle: the high initial capital investment required. Even where a technology offers potential savings over time, the upfront expenditure can make implementation difficult. This creates a challenge for factories that must balance the immediate financial demands of an investment against its potential longer-term benefits.

The decision to adopt an energy technology is influenced not only by its technical suitability but also by how its costs and benefits are understood. In the tea industry, factory boards play a central role because they approve budgets and determine whether proposed investments proceed. Where the potential benefits of cogeneration are not fully understood, securing approval for the initial investment can be difficult.

The involvement of technically trained managers is therefore important. Their participation can help factory boards assess the technical and financial implications of proposed energy systems and understand the relationship between initial costs and potential savings.

Better-informed investment decisions are particularly important when considering technologies that require substantial capital expenditure.

The experience of the tea industry illustrates a broader consideration in energy management: the availability of a suitable technology does not automatically lead to its adoption. Financial constraints and the understanding of decision-makers can influence whether an investment proceeds, even when there is potential for improved energy utilization.

Renewable Energy Technologies and Practical Implementation

Renewable energy technologies are attracting growing interest among young engineers in Kenya. Solar photovoltaic (PV) systems are particularly popular because of their relative ease of design and installation. Their growing appeal provides opportunities for engineers to apply their knowledge in renewable energy, while solar thermal applications and biogas production offer other areas of interest.

Smart and AI-augmented energy monitoring systems are also emerging in commercial and industrial applications. In addition, solar drying, cooling, and biogas production present opportunities for sustainable energy enterprises. These applications demonstrate the variety of areas in which renewable energy technologies are being explored.

However, successful implementation depends on understanding the conditions under which a system will operate. One important challenge, particularly in biogas projects, is the difference between theoretical design and actual performance. A system may appear suitable based on its design assumptions but produce different results when exposed to the conditions at its installation site.

Biogas systems are influenced by local environmental conditions because they depend on biological processes. Temperature variations, for example, affect bacterial activity and can consequently influence the performance of the system. This means that the expected output cannot be considered independently of the environment in which the system operates. Careful assessment of local conditions is therefore essential when planning renewable energy projects. Research and continuous monitoring are also important in understanding how installed systems perform and whether they meet their intended requirements. In biogas applications, attention to environmental conditions and actual system output is particularly relevant to achieving the expected results and maintaining user satisfaction. These considerations highlight the importance of connecting theoretical design with practical operating experience. Renewable energy projects must be evaluated not only on the basis of their proposed designs but also in relation to their actual performance under local conditions.

Energy Storage and Industrial Electricity Demand

Energy storage is an important consideration in solar applications because the availability of solar electricity does not always coincide with the timing of energy demand. Solar photovoltaic systems generate electricity when sunlight is available, while some industrial operations continue to require power at night. This creates a need to consider storage when assessing how solar energy can meet the requirements of a facility.

Tea factories provide a clear example of this challenge. Their operations can require substantial amounts of electricity at night, when solar generation is unavailable. An energy storage system may therefore be considered as part of the effort to address these requirements.



However, the appropriate approach depends on the factory's operating patterns and electricity demand.

Storage planning requires a clear understanding of when energy is needed and which operations depend on a reliable electricity supply. The requirements of critical loads must be considered alongside the practical demands of the facility. A storage system should therefore be assessed in relation to the actual energy needs it is intended to serve.

Cost is another major consideration. The high cost of large-scale energy storage remains a barrier to implementation, making it necessary to evaluate proposed investments carefully. Decisions must balance operational requirements, the need to maintain power to critical loads, and financial feasibility.

The objective is to determine whether the proposed storage solution is appropriate for the facility's needs and whether the investment is economically practical. Energy storage should therefore be considered as part of an overall assessment of energy demand, operating schedules, reliability requirements, and cost.

Energy Auditing and Efficient Energy Use

Improving energy efficiency does not depend exclusively on adopting new technologies. Understanding how energy is currently used within a facility is equally important. Energy auditing helps identify inefficiencies and provides a basis for determining where improvements can be made.

Some inefficiencies arise from everyday operational practices. Lighting left on in unoccupied spaces, for example, results in unnecessary electricity consumption. Such practices can be addressed through better controls and greater awareness of energy use. Although these may appear to be simple issues, identifying them is an important part of improving energy management.

Accurate measurement of energy consumption is also essential. However, shared electrical wiring systems can make it difficult to determine how much energy is consumed by specific areas or operations. Where consumption cannot be clearly separated, identifying the sources of energy use and assessing the effectiveness of potential interventions becomes more challenging.

More segmented and precise monitoring can help address this problem. By obtaining clearer information about energy consumption, facilities can better understand their usage patterns and identify where cost-effective improvements may be appropriate. Accurate measurement therefore supports the broader purpose of energy auditing: understanding how energy is used and identifying opportunities to manage it more effectively.

Energy auditing, appropriate technology selection, and informed investment decisions are closely related. Understanding existing consumption provides a useful basis for determining whether a facility needs improved controls, alternative energy sources, storage, or other interventions suited to its operational requirements.

Conclusion

Renewable energy and storage engineering present important opportunities for Kenya to improve industrial energy efficiency and strengthen local engineering capacity. Hydropower diversification, thermal energy applications, cogeneration, solar photovoltaic systems, biogas, and energy storage all offer opportunities to address different energy requirements. The tea industry, in particular, demonstrates the potential of cogeneration while illustrating how high initial investment costs and limited understanding of technological benefits can influence adoption.

At the same time, renewable energy projects must be assessed in relation to actual operating conditions. Biogas systems demonstrate the importance of local environmental factors, research, and continuous monitoring, while solar energy applications highlight the need to match storage arrangements with electricity demand and financial feasibility. Energy auditing also remains important in identifying inefficiencies and supporting cost-effective improvements.

Kenya's engineering expertise provides an opportunity to strengthen local manufacturing of boilers, dryers, and industrial cookstoves, reducing dependence on imported equipment. Realizing these opportunities requires careful attention to technical requirements, investment costs, and the practical performance of energy systems.

Ultimately, effective renewable energy development depends on selecting appropriate technologies, understanding their operating conditions, and making informed decisions about how energy is generated, stored, and used. By addressing these practical considerations, Kenya can make better use of its renewable energy opportunities and strengthen the role of engineering in industrial energy management.

Balancing the Breeze and the Sun: Inside Kenya's Renewable Grid Challenge



Eng. Wanja Kinyua, PE, MIEK

Electricity Has No Patience.

The moment a Kenyan household switches on a kettle, a factory starts a motor, or an office building begins its working day, the power system has to respond. Generation must meet demand in real time, while frequency, voltage, and power flows stay within their operating limits. There is no pause between the decision to consume electricity and the system's need to supply it.

Across the country, different forms of generation answer to different conditions. In the Rift Valley, geothermal units run steadily, providing a stable baseline. Hydropower shifts with water levels and dam operating rules. Wind turbines in the north respond to wind conditions that change by the hour. Solar output rises and falls with daylight and cloud cover. All these sources feed the same grid, but each keeps its own rhythm. The sun is predictable, but not constant. The wind is renewable, but not obedient. Demand follows the routines of households, businesses, and industry, and its own peaks often arrive just as renewable output is moving in a different direction altogether.

Reconciling these patterns in real time has always been the central task of power-system engineering. What has changed is the growing share of generation whose output answers to weather and time of day rather than a dispatcher's instruction, layered onto rising demand and a network that must move power across considerable distances to reach it.

"Renewable" as One Thing?

For an engineer, installed megawatts matter. So does what those megawatts can actually do. A 100 MW geothermal plant and a 100 MW wind plant do not hand the system the same thing at the same time. Nameplate capacity describes what a plant can produce under design conditions. Running the grid demands something more exacting: knowing what is available at this hour, in this location, how quickly that can change, and whether the network has the capacity to carry it to where it is needed.

By December 2025, renewable sources made up 80.6% of Kenya's installed electricity capacity - 2,957 MW across geothermal, hydro, wind, and solar. Between July and December that year, renewables supplied 78.79% of the energy actually delivered to the grid. The two percentages sit close together, but the small gap between them is where variability does its work: capacity tells you what

could theoretically be produced, delivered energy tells you what the system could actually use, and the difference between the two is a measure of how much the grid had to compensate for along the way.

That gap widens in significance as demand grows. Kenya Power recorded a system peak of 2,362 MW in July 2025. The International Energy Agency's 2026 assessment places Kenya in Phase 3 of its variable-renewable-energy integration framework, a stage at which variability begins to shape day-to-day system operation rather than remaining a planning consideration.

Kenya Power's August 2026 assessment gives that framework a Kenyan face. Wind and solar supplied about 34% of the mix during daytime peak demand of roughly 1,900 MW, and 36% during low-load periods of about 1,200 MW. The utility noted that sudden swings in wind and solar output can move frequency and voltage enough to require other generation sources to respond quickly. The point is not that variable renewables are a problem to be managed away. It is that they carry an engineering cost, and the grid settles that account continuously, sometimes minute to minute rather than hour to hour.

Solar makes the timing question especially visible. As irradiance builds through the day, generation climbs with it. As afternoon gives way to evening, output falls away just as households return home and the evening peak begins to take shape - generation and demand pulling in opposite directions at the point in the day when the system can least afford it. Knowing how many megawatts of solar capacity exist somewhere on the grid tells the operator little on its own. What matters is the shape and timing of that generation, the expected demand curve running against it, the reserves standing by, and the condition of the network the power must travel through to arrive.

Weather forecasting, in this setting, sits alongside load forecasting as one of the inputs system operators plan around, rather than a peripheral service. A cloud bank drifting across a large solar installation can register as a measurable event on the system. A shift in wind speed across a large wind farm sends through its own kind of ripple, not unlike the ripple engineers spend their careers trying to filter out of a DC line, except here it runs through the whole network and has to be managed rather than removed. How much either one matters depends on what the rest of the system happens to be doing at that moment, which is why flexibility is built into daily operations rather than kept aside for rare emergencies.

Kenya does not have to choose between renewable generation and a reliable grid. The harder task is engineering the two into a single system that holds together under pressure.

The Balance

When renewable output shifts, something else on the system has to move to compensate. Sometimes it is another generating unit brought online. Sometimes it is standby capacity, a change in dispatch, a network adjustment, or support drawn from elsewhere on the grid. It works a little like the droop control built into every generator on the network: a small deviation triggers a proportional response, continuously, without waiting for a control-room decision. The system is being corrected constantly, in increments too small to notice, long before anyone would call it an imbalance. The objective never changes: keep generation and demand in balance while frequency, voltage, and power flows stay within their limits.

Geography complicates that balance considerably. Kenya's strongest renewable resources are rarely located near the centers that consume the most electricity. The 300 MW Lake Turkana Wind Power project makes the point plainly - its output depends entirely on the 430 km Loiyangalani Suswa 400 kV line carrying that power south into the rest of the system. For a network planner, that distance translates into impedance, voltage drop, thermal loading, and contingency planning, all at once, long before the question of megawatts even arises.

The line's vulnerability became concrete when six towers near Longonot collapsed along the Loiyangalani - Suswa corridor. KETRACO restored both circuits in 2025 and reinstated full N-1 contingency, meaning the line could once again withstand the loss of a single element without triggering a wider outage. The episode offered a practical lesson in renewable integration: generating the electricity is only the first half of the task. The network has to be capable of carrying it, including under conditions the original plan never anticipated.

Nor does the challenge end at the transmission line. At substations, shifting power flows bring their own demands - voltage has to be held within limits as generation and demand move independently of each other, and reactive power support, once a secondary concern, becomes central to how much renewable energy the network can actually absorb. Rabai illustrates the point quietly. KETRACO's Rabai STATCOM project pairs a ±120 MVAr STATCOM at 220 kV with a 100 MVAr shunt capacitor at 132 kV, built specifically to strengthen voltage stability and support renewable integration along the coastal network. A solar panel is visible from the road. A wind turbine is visible from kilometers away. The equipment that lets the network absorb what those two things produce sits inside a substation

fence, doing work that rarely makes it into the public conversation about renewable energy.

Sun Downer

Timing raises a separate problem of its own. Solar output peaks near midday and tapers toward zero by evening, on a schedule set by the sun rather than by when Kenyans actually need electricity. As solar fades, households return home, businesses wind down for the day, and other loads begin to dominate the demand curve - and the system has to carry that handover without interruption. Flexibility is what makes the handover possible. Hydropower can absorb part of the shortfall where water conditions allow. Conventional generation fills in where it is available and economical to run. Interconnections bring in support from neighboring systems. Forecasting buys the operator time - enough to stage reserves ahead of the transition instead of chasing it once it has already begun.

Storage changes the equation in a way none of these tools quite manage alone: it lets the system move electricity from one part of the day to another. A battery charged during a midday solar surplus can be held in reserve and discharged into the evening peak once solar output has dropped away, and it can respond to a frequency deviation in a fraction of a second, well ahead of what conventional plant can typically manage. Kenya's Ministry of Energy has identified battery storage for frequency regulation, voltage stability, absorbing higher shares of variable renewables, covering generation shortfalls, and easing network loading during peak hours.

What a battery is actually worth to the grid, though, has less to do with its size than with its address. Its value depends on where on the network it sits, what that part of the grid is short of, how much power it can deliver on demand, how long it can sustain that output, and which of those services is scarce at the moment it is called on. Two batteries with identical nameplates can be worth very different things to the system - the megawatt rating on the spec sheet was never the whole story, not for a battery and not for the wind and solar plants discussed earlier either.

A Different Kind of Power System

As wind and solar take up a larger share of the mix, the grid's value increasingly rests on its ability to anticipate change and act on it before it arrives rather than after. Forecasting has moved from a planning exercise into a routine part of daily operations. Standby capacity needs to be staged with a clearer sense of what renewable output is likely to do next. Network studies have to account for power flows that shift from one hour to the next instead of settling into a repeatable daily pattern. Protection and control schemes must be designed for a system whose behavior keeps changing rather than repeating itself.

Kenya's National System Control Centre reflects that shift directly, built to sharpen real-time monitoring, control, and dispatch as the country folds more variable generation into an increasingly intricate network. The engineering question facing the sector has moved past simple volume - how many megawatts Kenya can generate - toward coordination: what is available, where it sits, how fast it is changing, and where it needs to travel next.

None of these pieces stand on their own. A wind farm is only as useful as the transmission line evacuating its output. That line cannot be planned in isolation from what is connecting to it. A substation is not merely a point on a map once the voltage around it starts to shift with the weather. A battery's megawatt rating says little without knowing which service the network actually needs from it at that hour.

Kenya does not have to choose between renewable generation and a reliable grid. The harder task, and the more interesting one, is engineering the two into a single system that holds together under pressure.

The wind will keep changing.

The sun will keep rising and setting.

Demand will keep moving to the rhythm of the households, businesses and industries the grid exists to serve.

Somewhere behind every switch flipped and every motor started, an operator, a set of reserves, and a network built for exactly this moment are already holding the balance.

To the consumer, electricity is electricity.

To an engineer, it is a system in motion - balancing the breeze and the sun.

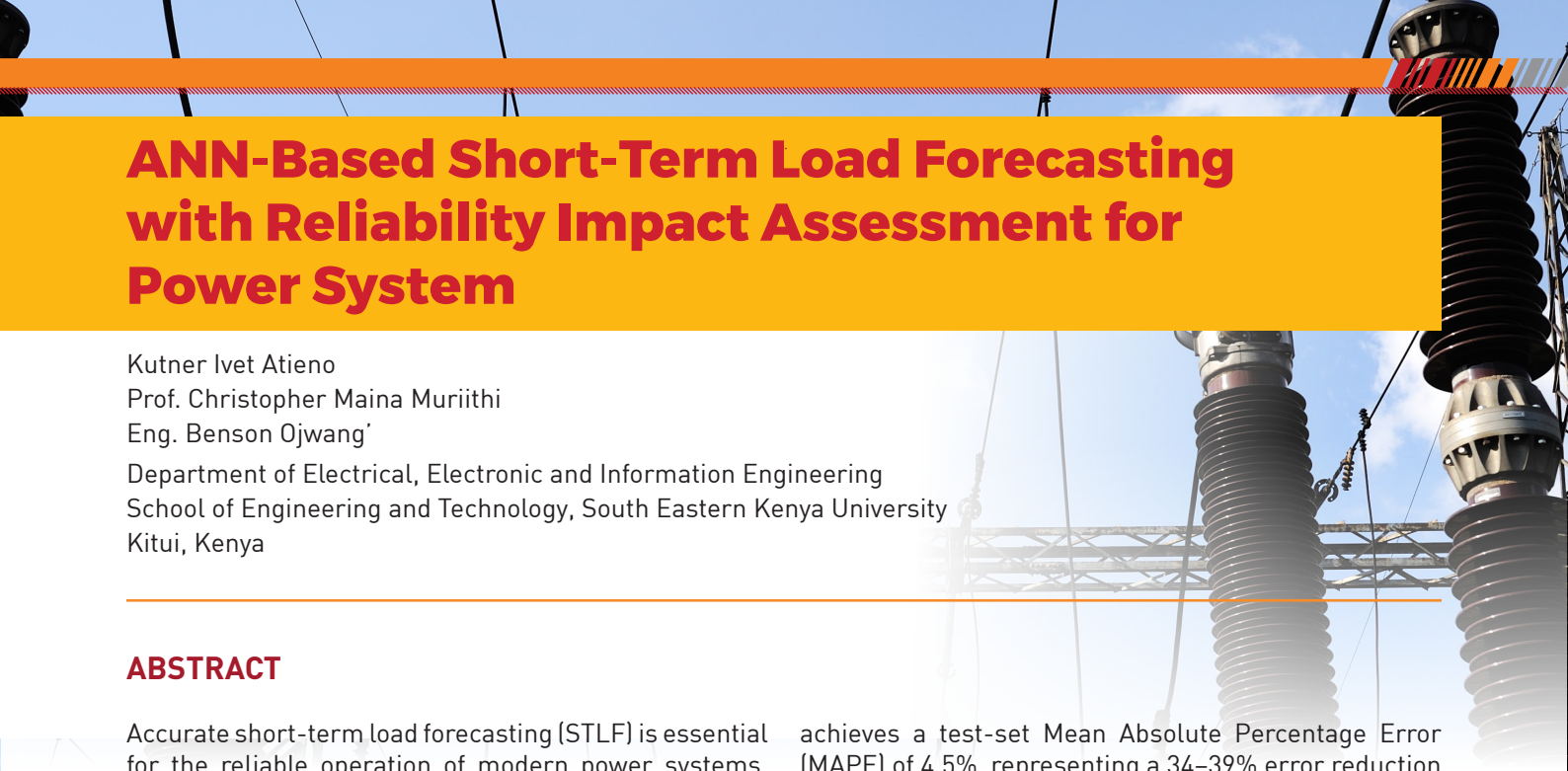
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ANN-Based Short-Term Load Forecasting with Reliability Impact Assessment for Power System

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ABSTRACT

Accurate short-term load forecasting (STLF) is essential for the reliable operation of modern power systems. Conventional statistical methods fail to capture the nonlinear relationships inherent in electrical load patterns, leading to prediction errors and reduced grid reliability. This paper presents an Artificial Neural Network (ANN)-based STLF model designed to improve load prediction accuracy and support enhanced grid reliability. Historical load, weather, and calendar data were sourced and the data's temporal and meteorological characteristics are representative of mixed residential-commercial feeders. The ANN achieves a test-set Mean Absolute Percentage Error (MAPE) of 4.5%, representing a 34–39% error reduction over a conventional regression baseline. A DC load-flow contingency simulation, in which forecast errors exceeding 5% triggered line overload events mapped via IEEE 33-bus protection constraints, yielded a 43.8% reduction in the System Average Interruption Frequency Index (SAIFI) and a 48.9% reduction in the System Average Interruption Duration Index (SAIDI). These results confirm that ANN-based forecasting constitutes a viable approach for enhancing grid reliability in modern smart power systems.

Key words: Short-Term Load Forecasting (STLF), Artificial Neural Network (ANN), Back-propagation, Grid Reliability, SAIFI, SAIDI, Power Systems.

I. INTRODUCTION

Load forecasting is a fundamental requirement in the planning and operation of electrical power systems. Power utilities must continuously balance electricity generation with consumer demand to maintain system reliability. The challenge of demand variability, particularly during peak hours, extreme weather conditions, and public holidays, was observed during an industrial attachment at Kenya Power and Lighting Company (KPLC), which motivated this study [1].

Conventional load forecasting techniques rely heavily on statistical models such as auto-regressive integrated moving average (ARIMA) and multiple linear regression (MLR), which are limited in handling nonlinear and complex demand patterns [2]. These limitations lead to inaccurate predictions, affecting grid reliability and causing unnecessary load shedding and renewable energy curtailment [3].

Artificial Neural Networks (ANNs) have emerged as powerful tools for short-term load forecasting due to their ability to learn nonlinear mappings between inputs and outputs without prior assumptions about the data distribution [4], [5]. In the context of smart grid systems, AI techniques, including ANNs, deep learning, reinforcement learning, and support vector machines, have been demonstrated to significantly enhance energy management, fault detection, and demand response [6], [7].

A key gap in existing literature is that studies predominantly focus on accuracy metrics without explicitly linking forecasting performance to grid-level reliability outcomes. This paper addresses that gap. Kenya's grid presents a particularly relevant context: For instance, KPLC manages a peak demand of approximately 2,000 MW, supplied by a mix dominated by geothermal generation (48%), complemented by wind power from the Lake Turkana Wind Power project and a growing solar photovoltaic fleet. Accurate STLF directly supports economic dispatch, reserve margin management, and integration of these variable renewable resources. The key contributions of this work are: (1) a reproducible ANN-based STLF system built on open-source tools and public datasets; (2) an extended evaluation framework incorporating power system reliability indices (SAIFI, SAIDI, CAIDI); and (3) a practical deployment architecture bridging academic research and utility operations.

II. LITERATURE REVIEW

A. Overview of Short-Term Load Forecasting

Short-term load forecasting covers prediction horizons from one hour to one week and is essential for generation scheduling, spinning reserve management, and real-time security assessment [8]. STLF is directly linked to grid reliability because errors in demand prediction propagate into scheduling decisions, potentially causing either overloads or forced outages [9]. The principal functions of STLF, as articulated by Gross and Galiana [8], include: (1) driving economic generation scheduling; (2) enabling proactive network security assessment; and (3) furnishing dispatchers with timely, accurate demand projections. These functions are illustrated in the classical block-diagram framework widely adopted in the power systems literature [10].

B. Conventional Forecasting Methods and Their Limitations

Traditional STLF methods include linear regression, exponential smoothing, Box-Jenkins ARIMA, and Kalman filtering [11]. While computationally efficient, these approaches assume linearity and stationarity in load data—assumptions that are violated by the complex, weather-sensitive, and behaviorally driven nature of real electrical demand [12]. Their failure to capture peak-hour anomalies and holiday effects is well-documented [13].

C. Neural Networks in Power Systems

Park et al. [14] pioneered ANN application to electric load forecasting, demonstrating superiority over regression in handling nonlinear load characteristics. Hagan, Demuth, and Beale [4] provided the mathematical foundations for multilayer feedforward networks trained with backpropagation, which remain the basis of most contemporary STLF models. Hong and Fan [15] demonstrated the importance of incorporating exogenous variables—particularly weather data—to improve probabilistic load forecasting accuracy. Raza and Khosravi [2] systematically reviewed ANN architectures for smart grid load forecasting, identifying model architecture, input variable selection, and training algorithm as the key determinants of accuracy.

More recently, deep learning architectures—particularly Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) networks—have achieved state-of-the-art STLF performance by explicitly modelling sequential temporal dependencies [16], [17]. Kong et al. [18] demonstrated that LSTM networks outperform feedforward ANNs on residential short-term load forecasting benchmarks. Gradient-boosting methods such as XGBoost have also achieved competitive accuracy with lower computational overhead [22]. Table I summarises comparative MAPE ranges from the literature; the present work's ANN serves as a reproducible baseline, with LSTM and GRU identified as primary future-work directions.

Table I. Comparative Stlf Methods (Literature)

Method	MAPE (%)	Temporal	Complexity	Ref.
MLR	7–9	None	Low	[11]
ANN	4.5	Feature-eng.	Medium	This work
XGBoost	3.8–5.2	Limited	Medium	[22]
LSTM	2.5–4.1	Explicit seq.	High	[18]
GRU	2.8–4.3	Explicit seq.	High	[17]

In the context of smart grid AI applications, Kayan Kılıçetal. [6] comprehensively surveyed AI techniques across demand forecasting, fault detection, voltage control, and renewable energy integration, confirming the growing centrality of machine learning in grid management. Omitaomu and Niu [19] corroborated these findings, highlighting the role of ANNs and reinforcement learning in smart grid stability and security.

III. METHODOLOGY

A. System Architecture

The proposed system follows a four-stage pipeline: data collection, pre-processing, neural network design and training, and performance evaluation. The ANN model was implemented in Python using NumPy, Pandas, and Matplotlib, and deployed through a full-stack web application with a Flask back-end served via ngrok and an HTML/CSS/JavaScript front-end.

B. Data Collection and Pre-processing

Historical electrical load demand data, temperature, humidity, and public holiday indicators were sourced from the UCI Machine Learning Repository Household Electric Power Consumption dataset [33], providing over two million hourly observations (January 2007–December 2010). Although the dataset does not originate from KPLC, its temporal resolution, diurnal demand patterns, and temperature sensitivity are representative of mixed residential-commercial feeder behaviour comparable to sub-Saharan African grids of similar peak-demand magnitude. The dataset was split into training (70%), validation (15%), and test (15%) subsets. Pre-processing steps included: removal of missing values via interpolation, min-max normalization to the range [0, 1], and feature engineering to extract time-of-day, day-of-week, and month-of-year indicators.

C. Neural Network Architecture

A multilayer feedforward neural network was designed with the following configuration: an input layer receiving seven features (historical load, temperature, humidity, hour-of-day, day-of-week, month, and public holiday flag); two hidden layers of 64 and 32 neurons respectively,

each using the Rectified Linear Unit (ReLU) activation function; and a single linear output neuron producing the forecasted load in MW. Weight initialization followed the Xavier/ Glorot scheme [34], and the Adam optimizer with a learning rate of 0.001 was used for gradient descent optimization. Back-propagation computed gradients of the Mean Squared Error loss function through the chain rule, as formalized by Rumelhart, Hinton, and Williams [20].

The architecture and hyperparameters were selected through systematic trial-and-error grid search over hidden layer sizes {32, 64, 128} and learning rates {0.0001, 0.001, 0.01}. The configuration of 64 and 32 neurons with a learning rate of 0.001 was retained based on validation loss minimization, achieving the lowest validation MSE without excessive model complexity. The mathematical operation of each neuron is given by:

$$Z = \Sigma(w_i \cdot x_i) + b, \quad \hat{y} = f(Z)$$

where x_i are the input features, w_i are the synaptic weights, b is the bias, and f(·) is the ReLU activation function defined as f(Z) = max(0, Z). The cost function minimized during training is the mean squared error:

$$C = (1/N)\ \Sigma_i\ (\hat{y}_i - y_i)^2$$

D. Performance Evaluation Metrics

Model accuracy was quantified using Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Mean Absolute Percentage Error (MAPE). In addition, the practical grid-level impact was assessed via three standard reliability indices: SAIFI, SAIDI, and CAIDI [21].

Reliability index values were derived by applying a DC load-flow-based contingency simulation to the IEEE 33-bus distribution test feeder. Forecast errors exceeding 5% of actual demand were mapped to line overload events using protection relay constraints. Overloaded lines triggered protection operations counted as interruption events contributing to SAIFI and SAIDI per IEEE Standard 1366-2012 [21]. This framework was applied identically to both ANN-based and conventional forecast inputs to ensure a fair comparison.

To address prediction uncertainty, 95% confidence intervals were estimated for the test-set forecasts using a Monte Carlo Dropout approach—dropout (rate 0.1) was applied at inference time over 100 stochastic forward passes. This provides probabilistic bounds on each point forecast, supporting reserve margin scheduling under demand uncertainty [29].

IV. RESULTS AND ANALYSIS

A. Training Convergence

The neural network was trained over 100 epochs with the Adam optimizer. Table II shows the loss progression at selected checkpoints. Both training and validation MSE decreased consistently and monotonically across all epochs, with a training-validation gap of less than 5% at epoch 100 (Training MSE = 341.6 MW², Validation MSE = 353.8 MW²). No significant over-fitting was observed based on the training-validation gap remaining below 5% throughout training.

Table Ii. Training And Validation Loss Progression

Ep.	MSE Tr.	MAE Tr.	MSE Val	MAE Val	RMSE Val
1	1187.4	28.6	1203.1	29.2	34.69
10	894.2	21.4	912.5	22.1	30.21
25	612.8	17.8	638.4	18.5	25.27
50	445.3	14.2	461.7	14.9	21.49
75	378.9	12.5	391.2	13.1	19.78
100	341.6	11.4	353.8	11.9	18.81

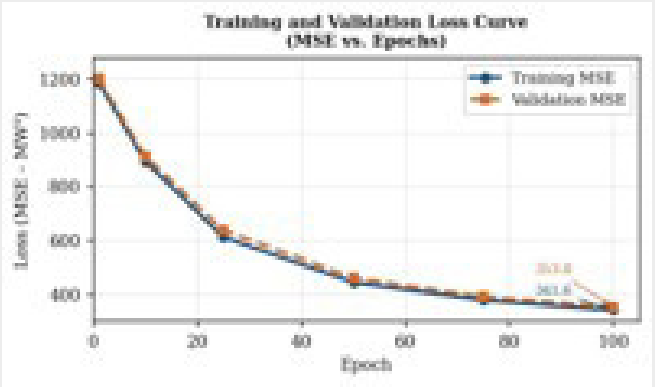


Fig. 1. Training and Validation Loss Curve (MSE vs. Epochs). The consistent downward trend in both curves confirms stable convergence with no significant overfitting.

B. Forecasting Accuracy Metrics

Table III presents the final model performance metrics on training, validation, and held-out test sets relative to a conventional multiple linear regression baseline. Results are reported as the mean over five independent runs; standard deviations are given in parentheses. A paired t-test comparing ANN and MLR test-set MAPE across five runs yielded t = 8.43 (p ← 0.001), confirming statistically significant improvement.

Table Iii. Model Performance Metrics — Ann Vs. Baseline

Metric	Training	Validation	Test
MAE (MW)	11.4 (±0.3)	11.9 (±0.4)	12.3 (±0.4)
MSE (MW²)	341.6 (±8.2)	353.8 (±9.1)	369.4 (±9.7)
RMSE (MW)	18.5 (±0.2)	18.8 (±0.3)	19.2 (±0.3)
MAPE (%)	4.1 (±0.1)	4.3 (±0.1)	4.5 (±0.1)

The ANN model achieved a test-set MAPE of 4.5%, indicating that on average its load predictions deviate by less than 5% from the actual demand—within the operationally acceptable range reported in comparable ANN-based STLF studies [14], [22]. The 34–39% error reduction across all metrics represents a substantial and consistent improvement over the conventional baseline.

C. Actual vs. Predicted Load

Fig. 2 presents a 48-hour overlay plot of the ANN model's predicted load profile against the actual measured load for a representative test day. The plot spans two complete diurnal cycles and demonstrates the model's ability to track peak demand periods, off-peak troughs, and mid-day plateaus.

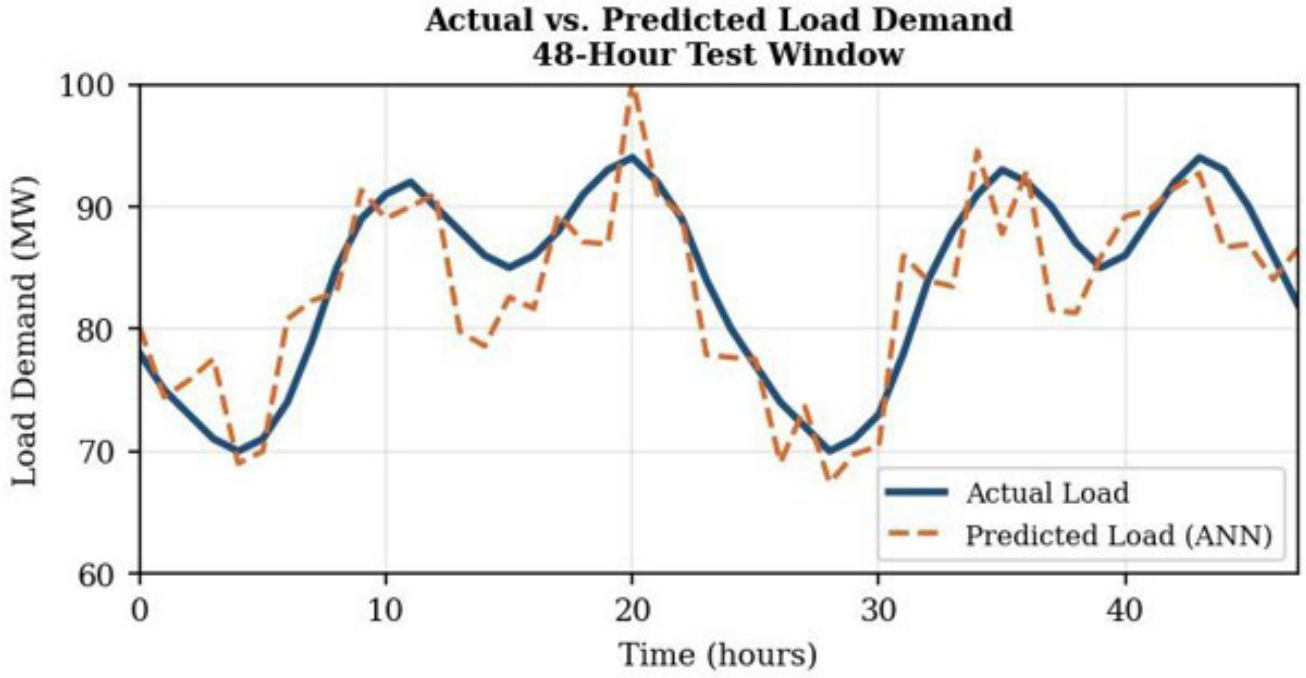


Fig. 2. Actual vs. Predicted Load Demand — 48-Hour Test Window. Time (hours) on x-axis; Load Demand (MW) on y-axis. The ANN model (dashed) closely tracks actual demand (solid) with a maximum instantaneous deviation of approximately 18 MW.

The model successfully captures the characteristic dual-peak demand pattern, morning and evening peaks, typical of residential and mixed commercial load profiles. The maximum instantaneous deviation of approximately 18 MW occurs at the onset of the evening peak ramp, a period of rapid demand increase that is inherently difficult to forecast precisely due to its sensitivity to weather and behavioral variability.

D. Prediction Error Distribution

Fig. 3 presents the distribution of residuals (actual minus predicted) across the entire test set. A well-behaved forecasting model should exhibit errors approximately normally distributed and centered near zero.

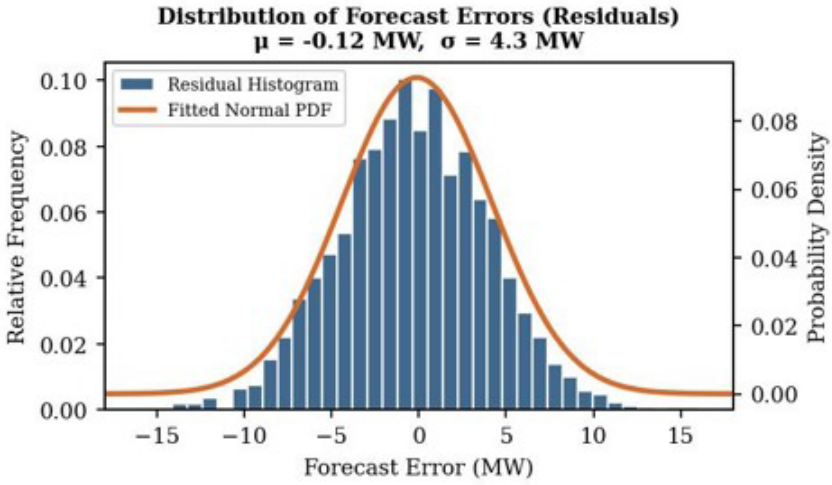


Fig. 3. Distribution of Forecast Errors (Residuals). Forecast Error (MW) on x-axis; Relative Frequency on y-axis. The distribution approximates a zero-centered normal curve (μ = μ0.12 MW, σ = 4.3 MW), confirming negligible systematic bias.

The error distribution is approximately bell-shaped and centered at μ = −0.12 MW, confirming negligible systematic bias. With σ = 4.3 MW, approximately 68% of individual predictions fall within ±4.3 MW and 95% within ±8.6 MW of the true demand. The slight negative skew (tendency to over-predict) is a conservative bias that is preferable in power system operations as it reduces under-provisioning risk [23]. Monte Carlo Dropout-derived 95% prediction intervals had a mean half-width of ±8.1 MW on the test set.

E. Power System Reliability Index Evaluation

Table IV presents the simulated reliability index comparison between the conventional and ANN-based forecasting approaches. ANN-based forecasting reduces SAIFI by 43.8% and SAIDI by 48.9%, demonstrating that the improved forecasting accuracy translates directly into measurable grid-level reliability gains.

Table Iv. Simulated Reliability Index Comparison

Index	Conv.	ANN	Impr.
SAIFI (ev/cust/yr)	3.2	1.8	−43.8%
SAIDI (hrs/cust/yr)	4.5	2.3	−48.9%
CAIDI (hrs/event)	1.41	1.28	−9.2%

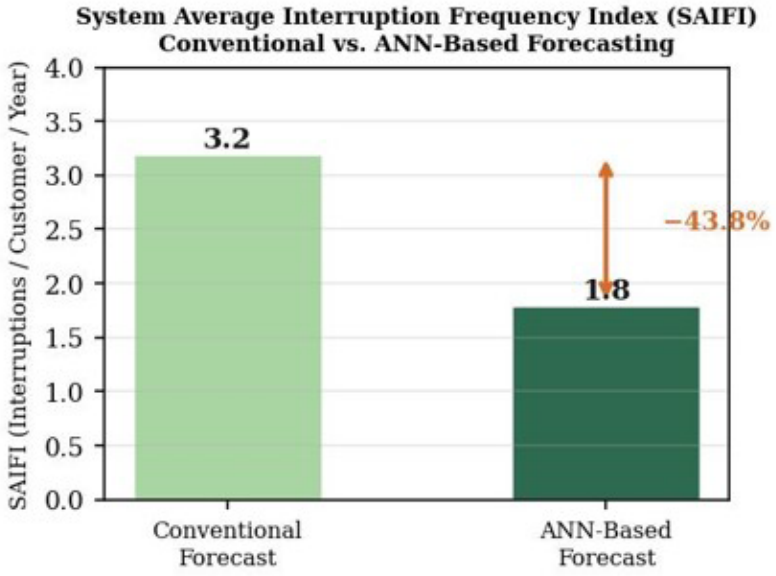


Fig. 4. SAIFI Comparison — Conventional vs. ANN-Based Forecasting. Forecasting Method on x-axis; SAIFI (Interruptions/ Customer/Year) on y-axis. ANN-based forecasting reduces average interruption frequency by 43.8%.

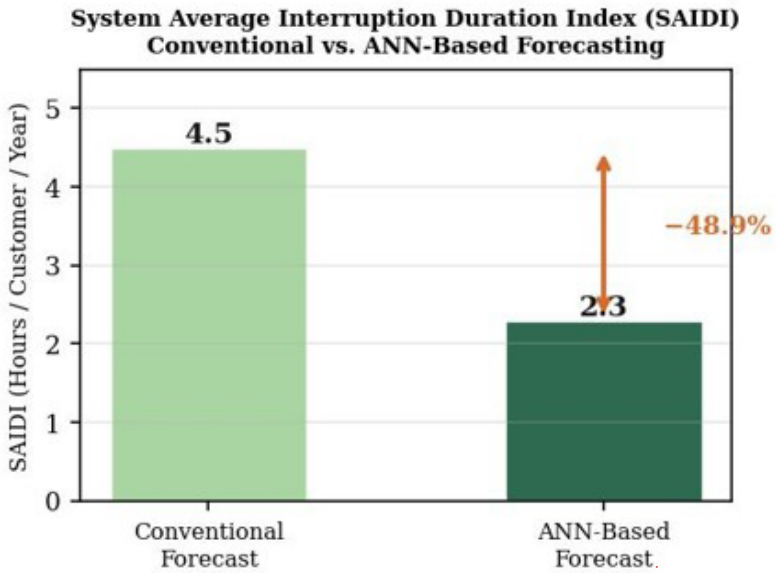


Fig. 5. SAIDI Comparison — Conventional vs. ANN-Based Forecasting. Forecasting Method on x-axis; SAIDI (Hours/Customer/ Year) on y-axis. ANN-based forecasting reduces average interruption duration by 48.9%.

The SAIFI reduction from 3.2 to 1.8 events per customer per year indicates that more accurate demand predictions allow grid operators to pre-position generation reserves more effectively, avoiding overload-induced forced outages. The near-49% SAIDI improvement confirms that fewer and shorter interruptions occur when dispatch scheduling is informed by ANN forecasts rather than conventional regression estimates [24]. The comparatively modest CAIDI improvement (9.2%) is consistent with the fact that restoration response time is influenced by operational logistics beyond the forecasting model's direct influence.

V. DISCUSSION

The results presented in Section IV demonstrate that the ANN model delivers consistent, measurable performance improvements across all evaluation dimensions. The test-set MAPE of 4.5% is consistent with the performance range of 2–5% reported by Park et al. [14] for ANN models trained on utility-grade datasets with full weather integration, and with the probabilistic forecasting baselines evaluated by Hong and Fan [15]. The fact that comparable accuracy is achieved using a publicly available dataset and a student-implemented Python model confirms the accessibility and reproducibility of the ANN approach.

The progressive and stable loss trajectory observed across 100 training epochs—with no divergence, oscillation, or rising validation curve—confirms that the back-propagation algorithm is correctly navigating the loss surface. The absolute MSE values (Training: 341.6 MW^2, Validation: 353.8 MW^2), while relatively large, are consistent with early-stage training of a model operating on load values in the 60–100 MW range, and are expected to reduce substantially with extended training [25].

The integration of power system reliability indices into the evaluation framework extends beyond the purely statistical error-metric approach common in the STLF literature [2], [8], providing a more operationally meaningful assessment of the model's real-world value. The 43.8% SAIFI and 48.9% SAIDI improvements have direct economic and social implications: fewer forced outages reduce revenue losses for utilities and disruption costs for customers, particularly in the Kenyan context where load shedding carries significant economic consequences [26]. Improved STLF accuracy reduces such events by enabling better generation scheduling and reserve margin allocation, which is critical given Kenya's growing renewable penetration—geothermal provides baseload stability, while wind and solar introduce variability that amplifies the importance of accurate demand forecasting for net load balance.

The full-stack deployment—comprising a trained neural network, a Python REST API, and an interactive web front-end—demonstrates that the system is not merely a research prototype but a practically deployable tool. This deployment architecture provides a blueprint for technology transfer from academic research to utility operations, addressing the implementation gap identified by Omitaomu and Niu [19] and Babu et al. [27].

VI. LIMITATIONS AND FUTURE WORK

The primary limitation of the current study is that the model was trained on a general-purpose dataset that does not capture the specific seasonal, cultural, and infrastructural characteristics of the Kenyan grid. Integration of historical load data from KPLC would substantially improve the model's relevance for operational deployment.

The training process has not yet fully converged at 100 epochs. Future work should: (1) extend training to 300–500 epochs; (2) implement learning rate scheduling such as cosine annealing; (3) add dropout regularization to further reduce overfitting risk; (4) explore LSTM and GRU recurrent architectures that explicitly model temporal dependencies [16], [17], [18]; and (5) develop a hybrid ANN-ARIMA ensemble that captures both linear trends and nonlinear residuals [28]. Additional future directions include: probabilistic load forecasting with confidence interval estimation using Monte Carlo Dropout or Bayesian neural networks [29]; extension to net load forecasting integrating Kenya's geothermal, wind, and solar assets [30]; federated learning for privacy-preserving multi-utility collaborative model training [31]; and real-time deployment on KPLC SCADA data streams.

VII. CONCLUSION

This paper presented the design, implementation, and evaluation of an Artificial Neural Network-based short-term load forecasting system for power systems. The ANN model achieves a test-set MAPE of 4.5%—a 34–39% error reduction compared to a conventional regression baseline—while maintaining stable and progressive training convergence with no significant over-fitting observed based on the training-validation gap remaining below 5%. Simulated grid operation scenarios, using a DC load-flow contingency model on the IEEE 33-bus feeder, yield a 43.8% reduction in SAIFI and a 48.9% reduction in SAIDI, providing concrete quantification of the reliability gains delivered by intelligent forecasting. The full-stack web deployment demonstrates practical applicability beyond the laboratory.

These results confirm that ANN-based forecasting is a superior and practically viable alternative to conventional load prediction methods for enhancing grid reliability in modern power systems. The path from the system developed in this work to a fully production-deployed utility tool is clearly defined, and the technical foundation—the trained model, the deployment architecture, and the comprehensive evaluation methodology—provides a credible and reproducible starting point for that journey. Power utilities, including KPLC, are encouraged to consider AI-driven forecasting tools as integral components of their operational planning frameworks.

ACKNOWLEDGMENT

The author gratefully acknowledges the supervision and guidance of Prof. C. Maina Muriithi throughout this project. Special thanks to Kenya Power and Lighting Company (KPLC) for providing the practical context and industrial experience that motivated this research. Gratitude is also extended to the IEEE for online training resources on machine learning and artificial intelligence, and to family and friends for their continued support. The UCI Machine Learning Repository is acknowledged for providing the open-access dataset used in model training and evaluation.

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Power on Demand: Inside Kenya's Race to Build a Smarter, More Resilient Grid



Bio Data: Jane Munyi is a Civil and Structural Engineer with experience in design, construction supervision, and project coordination. Her work and interests centre on sustainable construction, renewable energy, and resilient infrastructure, with a particular interest in Kenya's evolving energy sector. A keen researcher and lifelong learner, she has contributed to publications on sustainable construction materials, groundwater quality, and renewable energy. She is committed to applying technical knowledge to practical challenges and advancing solutions that create lasting value for communities and the environment.

Kenya's Clean Energy Imperative

Kenya stands at a defining moment in its energy journey. Population growth, expanding industries, and urbanization are driving demand for electricity that is reliable, affordable, and sustainable. The challenge is no longer simply generating more power, but ensuring that clean electricity can be integrated, transmitted, and delivered where it is needed. A reliable energy system is therefore essential to economic growth, improved livelihoods, and national energy security, while supporting Sustainable Development Goal (SDG) 7 and Kenya's Vision 2030 ambitions.

Kenya's Renewable Energy Advantage

Kenya has a strong foundation on which to build its clean energy future. According to the International Energy Agency's Kenya 2024 review, the country had around 3.3 gigawatts (GW) of installed generation capacity, including approximately 950 megawatts (MW) of geothermal, more than 800 MW of hydropower, and almost 800 MW from wind and solar combined. Since then, geothermal development has continued to advance, with Kenya surpassing 1,000 MW of installed geothermal power generation capacity, according to a 2026 publication by the Geothermal Development Company. This milestone further strengthens Kenya's position as a leading geothermal producer in Africa.

This diverse energy base spans multiple technologies and regions, from geothermal resources in the Great Rift Valley to strong wind resources in northern Kenya. The Ministry of Energy and Petroleum recognizes the 310 MW Lake Turkana Wind Power Project as Africa's largest wind farm. Solar power is also expanding, particularly for decentralized electricity access. The 55 megawatt-peak (MWp) Garissa Solar Power Plant, also recognized by the Ministry as one of the largest solar installations in East and Central Africa, further illustrates this growth. Together, these resources demonstrate that Kenya's advantage lies not in a single energy source, but in the breadth of its renewable energy portfolio.

From Generation to a Smarter Grid

Generating clean electricity is only the beginning. The challenge is delivering it efficiently from generation sites to consumers while maintaining a reliable, resilient grid. Grid congestion, transmission constraints, limited last-mile connectivity, and the cost of serving sparsely populated areas can hinder the integration of renewable energy and the reliable access it provides. Addressing these challenges requires more than expanding generation capacity; it calls for a smarter, interconnected system that can efficiently move, manage, and integrate power, as illustrated in Figure 1.

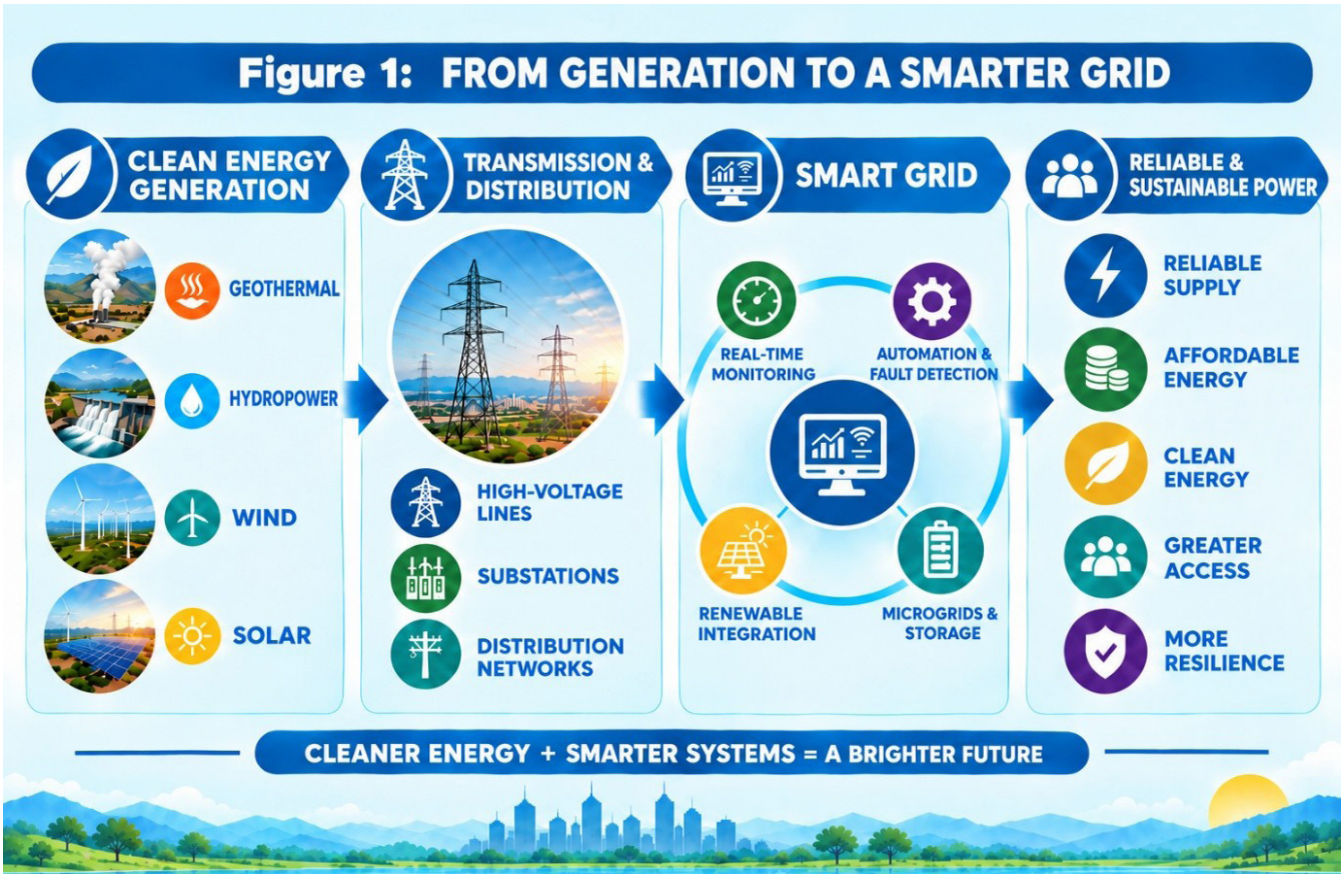


Figure 1: FROM GENERATION TO A SMARTER GRID

Clean Energy Generation → Transmission & Distribution → Smart Grid → Reliable, Sustainable Power

The next frontier is a smarter, more responsive grid. Digital monitoring, sensors, automated controls, and real-time data can improve power-flow management, detect faults, reduce losses, and integrate variable renewable energy.

As renewable generation expands, energy storage will become increasingly important. Batteries can balance supply and demand, store excess generation, and support grid stability.

Beyond the national grid, modular microgrids that combine solar, wind, small hydropower, and battery storage can deliver reliable electricity to rural and off-grid communities where extending the conventional grid is difficult or costly. Their modular design allows them to expand with demand, supporting broader access to electricity.

Building for a Changing Climate

A smarter grid must also be resilient. Power plants, substations, transmission lines, and distribution networks face risks from drought, flooding, extreme temperatures, and strong winds. Climate-resilient design, robust infrastructure, effective drainage, and risk-informed planning can reduce damage, minimize disruptions, and extend asset life. Building resilience requires combining robust infrastructure with informed planning, community participation, and collaboration, as illustrated in Figure 2.

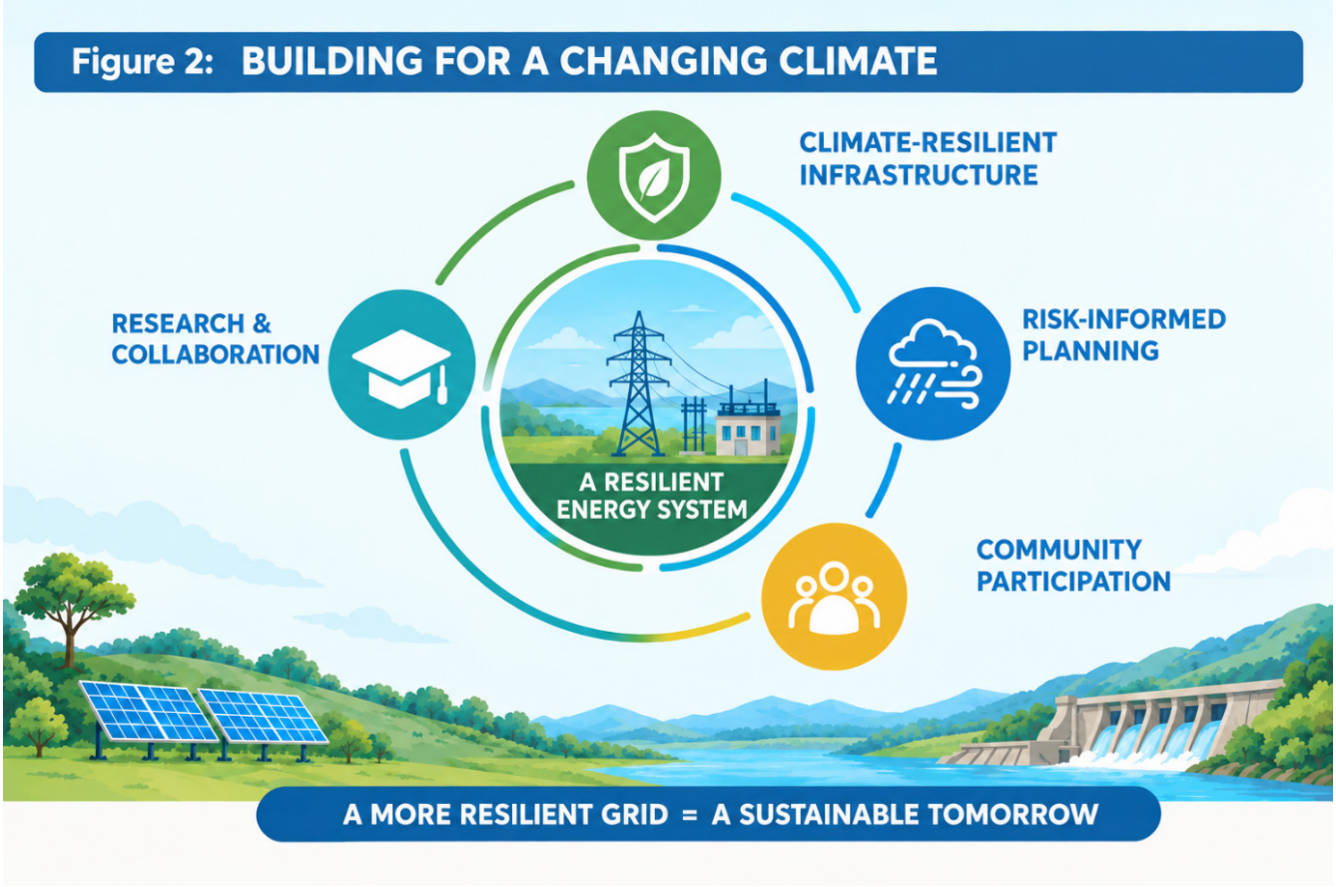


Figure 2: BUILDING FOR A CHANGING CLIMATE

Climate-Resilient Infrastructure + Risk-Informed Planning + Community Participation + Research & Collaboration → A Resilient Energy System → A Sustainable Economy

Infrastructure alone, however, cannot deliver a sustainable transition. Communities need opportunities to participate in energy projects from planning to operation and maintenance. Local involvement can strengthen social acceptance, incorporate local knowledge, and build skills needed to sustain decentralized systems.

Stronger collaboration among universities, research institutions, industry, government agencies, and communities is also essential. Practical training, knowledge transfer, and locally developed solutions can help ensure that Kenya's energy transition delivers lasting technical, social, and economic value.

Powering the Future We Want

Kenya has the renewable resources and ambition to build a cleaner, more secure energy future. The next challenge is connecting these strengths through smarter, more resilient, and more inclusive infrastructure. Kenya now has an opportunity to build a system capable of delivering the right power to the right places, at the right time.

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The Importance of Quality and Counterfeit Awareness in Kenya's Renewable Energy Market



Anvar Joseph Alot
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"Your competitor is selling it for less. Why should I buy from you?"

For anyone who has spent time selling, designing or delivering engineering solutions, this is a familiar question. It is also one of the most difficult questions to answer well because, on the surface, the comparison appears straightforward. Two products seem to perform the same function, yet one costs significantly less. The difficulty is that, in renewable energy, products that look similar are not always comparable.

My own experience across construction, sustainable energy and renewable energy operations has exposed me to technical products from several perspectives, as an engineer, a manager, a supplier and a customer. One lesson has remained consistent, price alone rarely tells the full story.

Affordability is important. Kenya needs solar and energy storage solutions that homes, businesses and institutions can afford. A lower-priced product is not automatically a poor product. The problem begins when equipment is presented as equivalent to a genuine product while the quality, capacity, safety or durability behind the label is very different. This is where legitimate renewable energy businesses are placed at a serious disadvantage.

A responsible company does not simply purchase a solar panel, inverter or battery and add a margin. It carries the cost of doing things properly. It must source equipment through traceable channels, verify suppliers and product quality, employ qualified technical personnel, undertake proper system design, provide electrical protection, comply with applicable standards, pay taxes and duties, maintain documentation, honor warranties and remain available when the customer needs support. There are also less visible costs such as engineering time, site assessment, testing, commissioning, troubleshooting, staff training, customer education, warranty administration and replacement of genuinely defective equipment. These costs are part of the product even though they do not appear on its casing.

When a customer buys from a legitimate engineering company, they are therefore buying more than hardware. They are buying **engineering assurance**. Confidence that the product is what it claims to be, that it has been selected correctly, that it will be installed safely, that its expected performance can be justified and that someone remains accountable after payment has been made.

A counterfeit or irresponsible trader can remove many of these costs and still sell a product that looks almost identical. The result is an unfair comparison. The compliant company is then asked to match a price achieved partly by avoiding the very safeguards that protect the customer. That is not healthy competition. It weakens legitimate businesses and gradually rewards poor practice.



> **"The cheapest renewable energy system is not necessarily the one with the lowest purchase price**

The concern becomes even greater as solar and battery storage expand. Two batteries may both be labelled 5 kWh, yet their actual performance can differ considerably. Cell quality, usable capacity, battery management systems, thermal protection, charge and discharge capability, cycle life and internal protection all matter.

A well-designed Battery Management System, for example, monitors key parameters such as voltage, current and temperature and helps protect cells against damaging operating conditions. A product may look impressive externally while containing inferior cells, inadequate protection or significantly less usable capacity than advertised.

This distinction matters because engineers design systems around declared specifications. Solar modules are selected based on output, voltage, current and environmental performance. Inverters are sized according to system loads and input characteristics. Conductors and protection devices are selected based on expected electrical conditions. Batteries are sized around usable capacity, autonomy, discharge rates and lifecycle expectations. If a component does not perform according to its declared specification, the assumptions used to design the rest of the system begin to fail.

It is also important to distinguish counterfeit products from legitimate low-cost products. A counterfeit product deliberately imitates or misrepresents another manufacturer or product. A substandard product may be sold under its own identity but fail to meet the safety, quality or performance that it declares. There is nothing wrong with a genuine 2 kWh battery being sold affordably as a 2 kWh battery. It may be exactly what a particular customer needs. The problem is when a product with much lower effective performance is marketed as a premium 5 kWh unit. Affordable engineering should be encouraged. Misrepresentation should not.

Counterfeit and substandard equipment do not only affect the customer who purchased them. They affect genuine businesses that invest in competent staff, compliance, warranties and after-sales support. These firms lose business because they are expected to compete against prices that may not reflect the same product quality or obligations. When a poor-quality battery fails prematurely, customers may conclude that lithium batteries are unreliable. When an inverter fails, the conclusion may be that solar technology itself is the problem. When an undersized or misrepresented system performs poorly, the installer, engineer and renewable energy industry can all lose credibility.

In this way, counterfeit products do more than take market share from legitimate companies. They **undermine confidence in the entire renewable energy transition.**

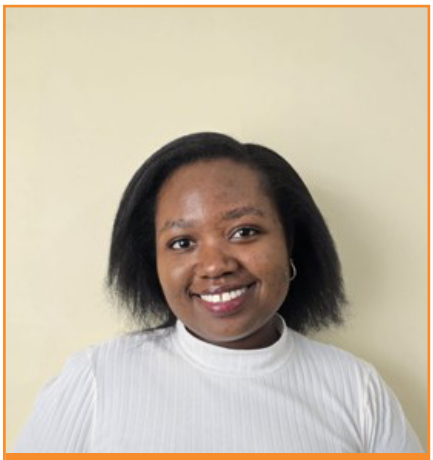
Ultimately, the cheapest renewable energy system is not necessarily the one with the lowest purchase price. Its true cost should be measured over its lifetime, considering the energy it actually delivers, its reliability and safety, maintenance requirements, lifespan, and whether there is someone accountable when something goes wrong. This is why the conversation around affordability must also consider value, performance and long-term reliability.

That is the conversation Kenya's renewable energy and energy storage sector needs. One that respects affordability while recognizing that quality, safety, accountability and engineering assurance come at a cost and that genuine businesses should not be penalized for providing them.



"Counterfeit products do more than take market share from legitimate companies. They **undermine confidence in the entire renewable energy transition.**

Power on Demand: Inside Kenya's Race to Build a Smarter, More Resilient Grid



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At 8:30 p.m. on 29 July 2026, large parts of Kenya suddenly went dark. Businesses, homes and industrial areas were left without electricity, renewing questions about the country's power infrastructure.

The blackout affected Nairobi, the Coast, Mt Kenya and parts of the Central Rift. Kenya Power's field teams worked through the night, and electricity was restored by 2 a.m. Although service returned relatively quickly, the interruption raised concerns about how well the grid copes during periods of high demand.

But a blackout does not mean renewable energy has failed. Kenya's electricity is largely clean: during the financial year ending June 2025, renewables supplied 80.17% of the country's electricity, led by geothermal, hydro, wind and solar.

Generating clean electricity, however, is only part of the job. The bigger challenge is making sure power is available when people need it, especially as demand grows and the grid must carry electricity across long distances.

"When an unexpected frequency dip or line trip occurs during high-demand hours, the whole grid feels the ripple effect," said Alex Kamau Wachira, Principal Secretary at the State Department for Energy. "Modernising our system with robust storage and smart balancing tools is critical to preventing these outages and securing our energy future."

The timing problem

Kenya's electricity demand usually peaks in the evening, between 7 p.m. and 9 p.m., according to the Energy and Petroleum Regulatory Authority. That is also when solar power is no longer available.

Between July and December 2025, peak demand reached 2,439.06 MW. By July 2026, it had climbed to a record 2,549 MW.

Solar power depends on daylight, while wind depends on local weather. Geothermal, by contrast, provides steady power around the clock. Hydropower can be adjusted quickly to meet changing demand, although rainfall affects how much water is available.

The challenge for engineers is to match electricity supply with demand, across different regions and times of day. This is where energy storage becomes important.

What can storage do?

A battery-energy-storage system can charge when there is extra electricity, such as late at night or during sunny afternoons and release it when demand rises.



Battery-energy-storage systems can store surplus electricity and release it during periods of high demand

EPRA identifies Kenya's mix of variable renewable energy, high geothermal capacity, low night-time demand and a small reserve margin as reasons to adopt battery storage. Batteries can help supply power during evening peaks and reduce voltage instability.

They can also respond quickly to changes in the grid. By reacting within milliseconds, batteries can help prevent a local fault from spreading into a wider blackout.

Kenya is already gaining experience with storage. In July 2025, KenGen commissioned a 1.16 MWh battery

system at its headquarters to support a 52 kW modular data center. The company has also set a target to develop 500 MWh of storage over the next decade.

KenGen is also studying a proposed 100 MW/100 MWh battery project for ancillary services, load balancing and load shifting across major substations.

At the same time, a World Bank-supported programme is assessing utility-scale storage needs in key areas, including the Central Rift, Coast, Mt Kenya, Nairobi, Northern Rift and Western Kenya.

Batteries are only part of the answer

While batteries are important, they cannot solve every problem on their own.

Storage cannot replace overloaded transmission lines or fix bottlenecks in the distribution network. EPRA has prioritized major projects, including the Mariakani 400/220 kV substation, the Konza 400/132 kV substation and intertie, and the Nanyuki-Isiolo 132 kV line to strengthen the grid, reduce losses and expand cross-border power transfers.

Managing demand also matters. Encouraging electric-vehicle charging and heavy industrial use during off-peak hours can move electricity consumption away from the evening peak, making better use of the existing network.

Kenya's future grid will need batteries, stronger transmission lines, digital monitoring, demand management and automated controls working together.

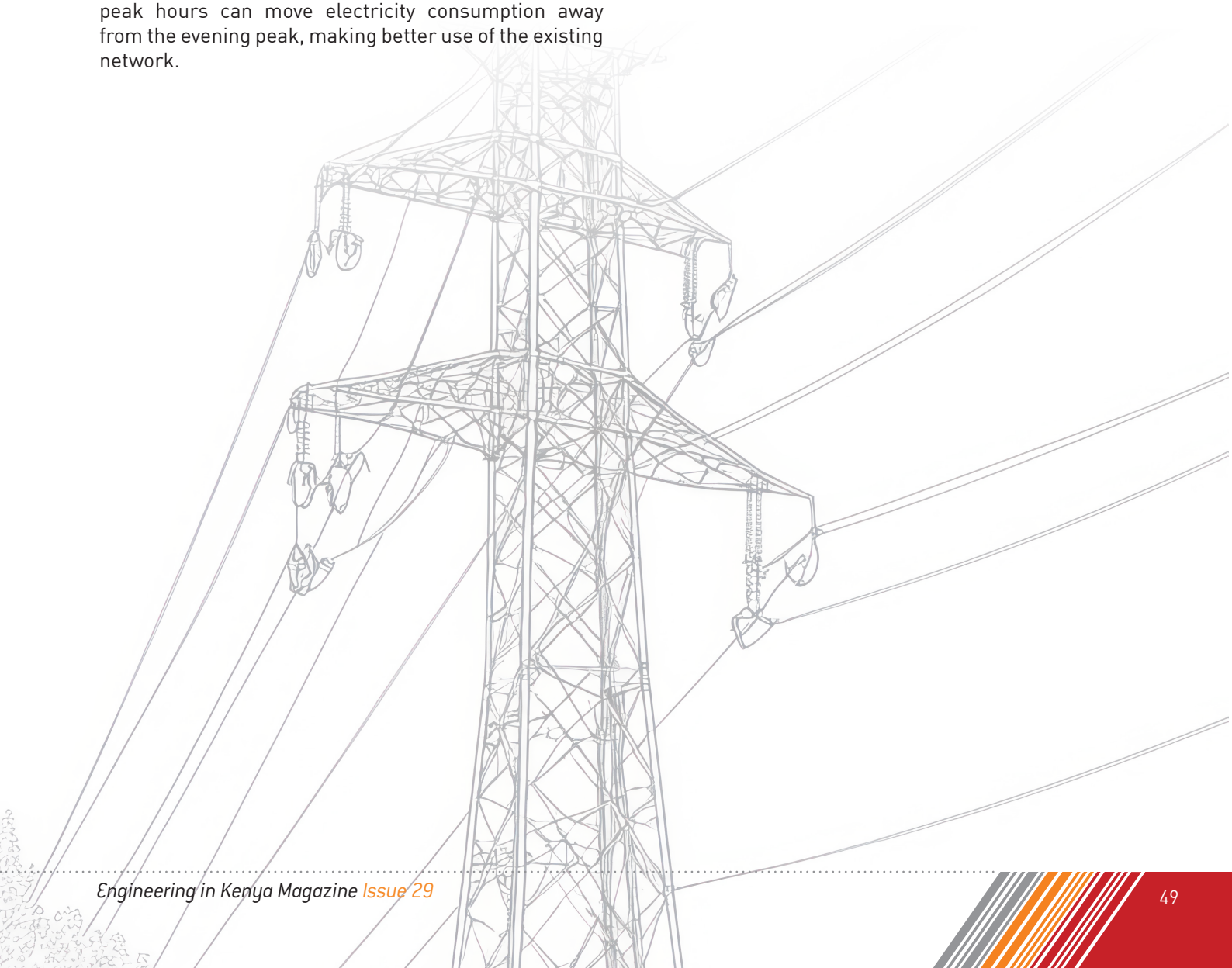
Building a grid that can respond

The goal is to build a flexible system that can deliver clean power when and where it is needed.

For Kenya's energy planners and political leaders, this is one of the defining challenges of the clean-energy transition: building an intelligent, modern grid that can provide reliable power on demand for years to come.

Ultimately, the goal demands building a flexible architecture capable of dispatching clean power precisely when and where it is needed most across every corner of the country.

For Kenya's energy planners and political leadership, this represents the defining challenge of the clean energy transition: building an intelligent, modern grid to deliver reliable power on demand for generations to come.



Closing the Circular Loop through Integrated Biodigesters and Biomass Briquetting Systems for Waste-to-Energy: Resource Recovery and Sustainable Value Creation



By Emmah Adhiambo Odhiambo

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Nairobi, the capital and largest urban center in Kenya, has an area of around 696 km² and a population of around 4.4 million as per the national census in 2019. Nairobi is the main commercial, administrative, and industrial center for the country. The city's rapid urbanization places a high demand on housing, transport, water supply, sanitation and importantly municipal solid waste management services.

The National Environment Management Authority (NEMA) estimates that the City produces approximately 2,400 tons of solid waste per day, with about 38% collected and a mere 10% recycled. Other more recent estimates are 3,068 tonnes per day of generation, of which 62.4% is organic material, but Nairobi City County related estimates put the generation at around 3,500 tones per day, with more than 60% of the material being organic. Combined, the daily amount of municipal solid waste generated on average is then about 2,400 to 3,500 tonnes of municipal solid waste.

This is a waste stream that is predominantly biodegradable organic material. The Nairobi City County estimate is over 60%, whereas the organic fractions reported in the Nairobi Integrated Solid Waste Management Plan are around 51%, while in the latest Ministry of Environment/JICA related materials, it is 60%. This translates to between 1200 and 2100 tonnes of organic waste per day in Nairobi based on a generation range of 2400-3500 tonnes/day. This fraction is a significant resource for not only anaerobic digestion, but also composting, nutrient recovery, and soil improvement in agriculture.

Dandora is the main official dumping point of the city and used to dump about 850 tonnes of solid waste each day, but this is outstripped by the site's capacity. Usually, waste is dumped in open areas, drainage ditches, rivers and informal dumpsites or is burned in the open. Low collections rates (reported to be just about 38% by NEMA) and poor recycling rates add to blocked drains, surface water and ground water contamination, greenhouse-gas emissions, air pollution and increased public-health hazards especially in low-income settlements close to waterways and disposal sites.

However, this waste-management challenge also provides a great opportunity to support circular economy interventions. Nairobi's waste contains a lot of organic waste material and is ideal for anaerobic digestion, which produces biogas for cooking, heating or generating electricity, while the digestate can be stabilized and used as organic fertilizer. Alternatively, dry biomass residues (like agricultural residues, wood waste, and some non-recyclable combustible residues) can be compressed to fuel briquetted form for energy use in households,



institutions, and industry. Combined with briquetting, this would thus facilitate Kenya's ability to significantly reduce the amount of waste disposed at Dandora and informal waste disposal centers, recover renewable energy and prevent methane production associated with uncontrolled decomposition, produce organic fertilizer and create green jobs in waste collection, sorting, processing, plant operation and distribution.

A combination of anaerobic digestion and biomass briquetting offers a great opportunity to utilize waste as a valuable resource in Nairobi. Wet organic waste can be converted into biogas and digestates, which is rich in nutrients, while suitable dry biomass residues can be converted into solid fuel briquettes.

By anaerobic digestion, biodegradable organic matter can be converted to biogas in the absence of oxygen. Food wastes, fruit and vegetable wastes, market residues and animal manure are suitable feedstocks. The resulting biogas can be used for cooking energy, process heat or electricity generation; digestate can be evaluated for agricultural purposes after proper treatment and quality checks.

Studies on organic waste from markets, households, farms, slaughterhouses and restaurants have reported yields of methane of around 230–441 milliliters per gram of volatile solids. Co-digestion of selected waste streams can enhance the production of biogas by up to 33%.

For instance, a processing plant for 10 tonnes of segregated organic waste per day might generate an estimate of 800-1,000m3 of biogas, which is an indicative yield of 80-100m3 per tons of waste fed into the plant.

The briquetting process takes the following types of dry residues as suitable and transforms them into compact solid fuels: sawdust, maize cobs, rice husks, sugarcane bagasse, crop stalks and woody pruning's. Using the appropriate equipment, the biomass is sorted, dried, reduced to suitable particle size and compressed. The result would be the production of briquettes which may be supplied to Schools, Hospitals, Hotels, Restaurants and Small Industries having suitable combustion appliance.

Kenyan studies on briquette-making and their use have identified the possibility of socio-economic benefits such as job creation and local development. A production example documented by the Kenya Forestry Research Institute (KEFRI) showed that the cost of electricity is at about Kes. 1 per kg briquette. This does not include feedstock, labour, drying, maintenance, packaging and distribution costs.

If technically and economically feasible, surplus biogas or recoverable waste heat would be used for drying biomass, thus diminishing the need for external energy. These two processes would therefore not compete for the same feedstock, but rather complementary waste streams would be used for the resources.

There is experience of small scale urban anaerobic digestion in Nairobi. In 2010, a pilot project of the use of kitchen waste for compact ARTI digesters was run from May to November in Nairobi city, involving the then City Council of Nairobi, the Japan International Cooperation Agency (JICA) and the United Nations Environment Programme (UNEP) under solid-waste management planning.

The pilot comprised of two residential (2.5 m^3 each) and one institutional (9.5 m^3) units. The reported capital cost per household unit was around €1,015 and for the institutional unit €2,237. The figures of these historical plants should not be interpreted as the present costs for installation, but rather serve as an example of how the use of biogas in the urban sector can proceed. In the light of this, a decentralized facility could be set up close to any of the major market, institutional kitchen cluster or agro-processing centers.

In conclusion, Nairobi landfills can be considered not just as garbage dumps, but a source of renewable energy and valuable resources that can be tapped. The city's population is increasing, leading to a growth in waste production and the strain on current waste management infrastructure. If there are no sustainable solutions, this waste will keep on polluting the environment, clogging drainage systems and exacerbating flooding, especially in heavy rainfall. Nairobi should not wait for these challenges to intensify, but rather leverage its waste problem as an opportunity. Combining anaerobic digestion with biomass briquetting enables us to turn organic waste into biogas, fertilizer and clean cooking fuel. Waste no longer needs to be regarded as a problem, but as a treasure - a renewable energy treasure that can power homes, generate jobs and build a cleaner, greener, more sustainable city.

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Driving Renewable Energy Innovation: The Role of Mechanical Engineering Research in Kenya's Clean Energy Transition

By Dr. Stephen M. Talai,
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Moi University

Kenya has made significant progress in renewable energy generation through geothermal, hydropower, wind and solar. However, the next phase of our energy transition must go beyond installing additional generation capacity. We must improve system efficiency, strengthen reliability, develop local maintenance expertise and translate research into technologies that address really economic and industrial needs.

My background in mechanical engineering, energy research and power plant maintenance has shaped my understanding of this challenge. Energy innovation is not simply about developing a technology that works; it is about ensuring that the technology is technically reliable, economically viable, maintainable and appropriate for the conditions in which it will operate.

Improving the performance of existing systems

Kenya's renewable energy resources provide a strong foundation for development, but the availability of generation does not automatically guarantee reliable electricity supply. Transmission and distribution losses, equipment failures, power quality problems and inefficient energy use can undermine the benefits of installed capacity.

I believe engineering research must therefore focus on the performance of the entire energy system. Opportunities include predictive maintenance, smart-grid technologies, efficient motors and pumps, transformer optimisation, power quality monitoring and demand-side management. For industrial facilities, monitoring electricity consumption alongside equipment operating conditions can help identify inefficient processes, abnormal loads and opportunities for energy recovery.

The principle is straightforward: the cheapest energy is energy we do not need to generate. Improving the efficiency of motors, compressors, pumps and thermal processes can reduce operating costs while easing demand on the electricity system. Research should establish the actual savings achieved under operating conditions rather than relying solely on manufacturers' specifications or laboratory results.

From laboratory research to industrial application

One of the major barriers to renewable energy innovation is the transition from a successful research project to a commercially viable product. A prototype may demonstrate good performance in a laboratory but still fail to meet the requirements of an actual user. Its cost, durability, safety, maintenance

needs, availability of spare parts and compliance with applicable standards must all be considered.

For example, a solar-powered agricultural dryer must do more than demonstrate that solar energy can remove moisture from crops. Researchers need to assess drying temperature, airflow, moisture removal rate, product quality, energy consumption and performance under changing weather conditions. The design must also be affordable, easy to maintain and suitable for the scale of the intended enterprise.

This is why I consider research funding, technology demonstration and commercialisation inseparable. Universities need stronger partnerships with industry so that research begins with identifiable problems and proceeds towards field testing and adoption. Manufacturers, potential customers and regulators should be involved where appropriate to establish whether a proposed technology meets practical requirements.

Building local engineering capability

Kenya must also strengthen its ability to manufacture, operate and maintain energy technologies locally. Importing equipment without developing the knowledge required to maintain it can increase operating costs and extend downtime when specialised repairs or replacement parts are needed.

Mechanical engineering offers opportunities in the fabrication of solar mounting structures, piping systems, heat exchangers, pressure vessels, pumps, solar thermal equipment and selected geothermal plant components. Local production, however, must be supported by appropriate materials, skilled fabrication, dimensional accuracy, quality assurance and testing. Components used in pressure systems and geothermal installations, for example, must satisfy demanding requirements for operating pressure, temperature, corrosion resistance and mechanical integrity.

Local research can help manufacturers adapt designs to Kenyan operating conditions and improve component performance. Universities can contribute through materials testing, computational modelling, prototype development and performance evaluation. The objective should not be to manufacture everything locally regardless of cost, but to identify components that can be produced competitively without compromising safety, reliability or quality.

Storage and the productive use of renewable energy

Energy storage is important where generation and demand do not coincide, but the appropriate technology depends on the application. Batteries may be suitable for electrical applications requiring flexible storage, while thermal storage can be more appropriate where the principal demand is heat. Pumped-storage hydropower can also provide longer-duration storage where suitable geographical conditions and infrastructure exist.

Research is needed to evaluate storage performance, system integration, lifecycle costs and end-of-life management. Batteries considered for second-life applications must be assessed for remaining capacity, internal resistance, safety and suitability for their proposed duty. Reuse should not proceed without appropriate testing and safeguards.

I am particularly interested in integrated renewable energy systems that connect generation to productive activities. Consider an agricultural processing system combining solar power, suitable storage, intelligent controls and a crop dryer. Biomass or biogas could provide supplementary energy where technically and economically appropriate. Such a system could help farmers reduce post-harvest losses while enabling small enterprises to process and preserve produce.

The same principle can be applied to maize drying and other agro-processing activities. Rather than developing a solar technology in isolation, we should consider the complete system: the energy source, conversion equipment, control strategy, storage requirements, processing load and economic value of the final product. This approach connects renewable energy innovation directly to industrialisation and employment creation.

Emerging applications, including renewable-energy-supported ammonia production and solar-powered cooking, also warrant research. Their feasibility must be established through technical evaluation, safety assessment and economic analysis before large-scale deployment.

Preparing engineers for the next phase

The future energy sector requires engineers who combine strong disciplinary knowledge with multidisciplinary skills. Mechanical engineers must understand thermodynamics, fluid mechanics, heat transfer, materials and machine design, but they increasingly need competence in data analytics, automation, control systems, simulation and artificial intelligence. These capabilities can support performance modelling, fault detection, energy forecasting and more efficient operation of integrated systems.

Engineers must also understand project finance, lifecycle costing, standards and certification. Improving a technology's efficiency is valuable, but its wider contribution depends on its cost, service life, maintenance requirements and ability to meet the needs of a real customer. Communication and teamwork are equally important because energy projects involve technical, commercial, regulatory and community considerations.

> Kenya's next stage of clean energy development should involve more than adopting technologies developed elsewhere. We need the capacity to adapt them to local conditions, manufacture selected components, maintain installed systems and develop solutions that can compete beyond our borders.

At Moi University, the Department of Mechanical, Production and Energy Engineering contribute to this development through postgraduate programmes, including the Master of Science in Sustainable Energy and Energy Access; the Master of Science in Energy Studies, Renewable Energy option and the Doctor of Philosophy in Energy Studies. These programmes support multidisciplinary learning and research into energy access, renewable technologies and their practical applications.

I see particular value in community engagement and industry-based research. Working with communities helps researchers understand local energy needs, while industry partnerships expose students to operational problems that require practical solutions. A dedicated Renewable Energy Research Hub could strengthen this relationship by enabling students and researchers to develop, test and refine integrated systems for agricultural processing, industrial applications and improved energy access.

From adoption to innovation

Kenya's next stage of clean energy development should involve more than adopting technologies developed elsewhere. We need the capacity to adapt them to local conditions, manufacture selected components, maintain installed systems and develop solutions that can compete beyond our borders.

Achieving this requires sustained investment in research, demonstration facilities, industry partnerships and technical training. It also requires evaluating innovations against measurable criteria: efficiency, reliability, safety, lifecycle cost, maintainability and practical value to users.

I believe mechanical engineering research can help bridge the gap between Kenya's renewable energy resources and its industrial ambitions. By connecting sound engineering with local manufacturing, productive energy use and commercialization, we can build a more reliable energy system while creating opportunities for innovation, enterprise and employment



By Kigen Kiprotich Leonard
Graduate Mechanical Engineer, Plant and Energy Engineering & Publishing Officer, IEK

Engineering Kenya's Energy Transition: Making Every Unit of Energy Work Harder

Solar panels, wind turbines, geothermal wells and batteries have become the public face of Kenya's energy transition. Less attention is given to the engineering behind them: how energy is converted, how heat and fluids move through equipment, how components hold up under operating conditions and how losses are controlled across the system. These decisions largely determine how well each technology performs.

As more renewable capacity comes online, the focus is shifting towards delivering useful energy to consumers reliably, efficiently and at a reasonable cost.

Kenya already has an established renewable energy base built on geothermal, hydropower, wind, solar and biomass, with growing interest in energy storage. In the 2024/25 financial year, renewable sources accounted for 80.17 per cent of the electricity generated in the country, with geothermal contributing 39.5 per cent from about 944 MW of installed capacity. The next stage calls for a systems approach that links generation to the people who use energy, including buildings, manufacturers, farms and health facilities. Many of these users need more than electricity. Depending on the process, they may require hot water, steam, refrigeration, cooling, drying, sterilization or heat at a specific temperature. Engineering the transition means matching the form and quality of the energy supplied to the task it is meant for.

Mechanical engineering fundamentals therefore have a central place in practical energy planning. Thermodynamics, heat and mass transfer, fluid mechanics, materials science, mechanical design and maintenance help determine whether renewable technologies operate efficiently, safely and sustainably under real conditions.

Delivering useful energy

Solar photovoltaic (PV) systems are a good example of why energy performance should not be judged by electrical output alone. A PV module converts sunlight into electricity, and its efficiency generally falls as the cells get hotter. For crystalline silicon modules, the most common type, efficiency drops by roughly 0.4 to 0.5 per cent for every degree Celsius above the 25°C at which panels are rated. Heat transfer by conduction, convection and radiation therefore affects the output of a technology usually thought of as electrical. Module spacing, mounting arrangements, airflow and ambient conditions all influence how well heat is dissipated, and should be considered during design and installation.



Where a site needs both electricity and heat, photovoltaic-thermal systems can make use of more of the available solar resource by generating power while recovering thermal energy. Whether this is worthwhile depends on the temperature and timing of the heat demand, the system cost, the space available and the maintenance required. In general, a renewable energy system should be assessed by the useful service it provides rather than by the energy captured at the first stage of conversion.

This is especially relevant to Kenyan industry. Food processors, dairy plants, hotels, hospitals, laboratories, agricultural enterprises and manufacturers use electricity, but many also need hot water, process heat, steam, refrigeration and drying. Globally, heat accounts for about two-thirds of the energy used by industry. In suitable applications, supplying heat directly from a renewable thermal source avoids the additional conversion steps involved when electricity is used to produce heat.





The Geothermal Development Company's pilot projects at Menengai are a local example. Brine from a low-pressure well passes through a heat exchanger that heats fresh water to 85°C, which is used for milk pasteurization, grain drying, heated fish ponds, greenhouses and a laundry. In each case, the design starts with the required temperature range, operating schedule and process demand, followed by the selection of a system that meets them safely and economically.

Recovering heat in industry

Thermodynamics allows engineers to trace energy through a process, assess conversion efficiency and identify where losses occur. In an industrial facility, energy leaves through exhaust gases, hot water, cooling streams, condensate and heated products. Some of this energy can be recovered where there are a suitable demand and a technically viable recovery method. One widely cited study estimates that about 72 per cent of the world's primary energy consumption is lost during conversion, with most waste heat streams below 100°C.

Heat exchangers transfer energy from a hot stream to a colder one without mixing the two. Exhaust-gas heat recovery, condensate return, process integration and heat pumps can reduce the primary energy needed for a given production output. The benefits depend on temperature differences, flow rates, contamination, pressure drop, operating hours, capital cost and maintenance. A recovery system should be assessed against the plant's full operating profile rather than an idealized operating point.

These measures can lower fuel or electricity demand, reducing operating costs and emissions, while better control of process temperatures supports product quality and equipment reliability. An energy assessment should examine the energy entering the facility, the useful output, the losses and the opportunities to reuse energy before it is released to the environment. In Kenya, the Energy (Energy Management) Regulations, 2012 require designated facilities to undergo an energy audit at least once every three years and to realize at least half of the recommended savings.

Conventional engineering still counts

The move to renewable energy does not make conventional mechanical engineering obsolete. Boilers, turbines, condensers, pumps, piping networks and heat exchangers remain essential in many energy and industrial applications, and their operating principles apply whether the energy comes from biomass, geothermal heat, solar energy or another source. Engineers still need to understand pressure and temperature conditions, flow behavior, heat transfer rates, mechanical stresses, corrosion, safety requirements and the maintenance needed to sustain performance over time.

Kenya's geothermal sector illustrates this well. Converting underground heat into electricity involves fluid extraction, pressure management, steam handling, piping, heat transfer, turbine operation, condensation, mechanical integrity and maintenance. The renewable nature of the resource does not remove these operational challenges, and sound engineering and long-term asset management remain essential to dependable output.

Mechanical engineering also contributes to thermal energy storage. Renewable electricity can be converted into heat and stored for later use, so that supply and demand do not have to coincide. Depending on the application, energy may be stored thermally, mechanically or electrically. The International Renewable Energy Agency projects that global thermal energy storage capacity could triple

to more than 800 GWh by 2030. The appropriate choice depends on the required storage duration, response time, scale, efficiency, cost and intended output, so storage should be selected according to the service it is expected to provide.

Designing for local conditions

Energy technologies operate within local climatic, industrial and economic conditions. Ambient temperature affects thermal performance, dust and other environmental factors influence operation and maintenance, and feedstock quality affects biomass and waste-to-energy systems. Industrial processes also differ in their temperature requirements, load profiles and tolerance for interruptions. Infrastructure, technical skills, access to spare parts and the availability of service providers further affect whether a system can be maintained over its intended life.

A technology that performs well in one setting may need to be adapted before it is technically and economically viable in another. Equipment selection should take into account installation conditions, expected duty cycle, maintenance access, safety, lifecycle cost and the skills available to operate the system. Field measurements and performance monitoring are important because actual conditions often differ from design assumptions.

Local design, fabrication and manufacturing offer another opportunity. Renewable energy projects create demand for generation equipment as well as mounting structures, heat exchangers, pressure vessels, pumps, piping, thermal systems and specialized mechanical components. Strengthening local capacity to design, manufacture, install and maintain this equipment can support industrial development, reduce dependence on imports and give engineers practical experience in adapting technologies to local needs.

Integrating the whole system

The value of an energy system depends on how well its components work together. A solar panel generates electricity, a battery stores it, a heat exchanger transfers thermal energy, a boiler produces steam, a turbine converts the energy in a working fluid into mechanical work, and a heat pump moves heat from one place to another. Each component has its own performance characteristics, but the overall result depends on how they interact.

This is particularly important in industrial facilities and critical buildings, where renewable generation may operate alongside storage, heating, ventilation and air conditioning (HVAC), backup power and process machinery. Reliability depends on system architecture, controls, thermal management, equipment sizing, maintenance planning and how components respond to changing loads. A high-performing component offers limited benefit if it is poorly matched to the rest of the system.

Mechanical engineers apply thermodynamics to energy conversion, fluid mechanics to the movement of water, steam and gases, heat transfer to thermal equipment, and materials knowledge to durability and safety. These skills need to be combined with electrical engineering, instrumentation, automation and data analysis, so that energy systems are maintainable, efficient and fit for purpose.

Linking research and industry

Universities, research institutions, industry and government all have roles in developing energy solutions suited to Kenya. Research can identify promising designs and improve understanding of system performance, but a laboratory result is only one stage on the way to adoption. A technology must also be tested under realistic operating conditions, engineered for manufacture, evaluated for safety and cost, installed, maintained and, where appropriate, commercialized.

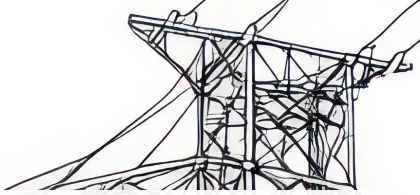
Closer links between research institutions and industry can help focus research on real operational problems. Industry-linked projects, field trials, demonstration installations and feedback from operators can reveal performance issues that may not appear in controlled settings. Practicing engineers can help turn research findings into equipment specifications, prototypes, operating procedures and maintenance plans.

Education and professional development should also prepare engineers to work across energy sources and end uses. A practitioner may need to understand how thermal equipment interacts with an electrical load, how waste heat can be recovered, how storage changes plant operation or how local conditions affect performance. Engineers who can assess whole systems, work across disciplines and validate solutions with operating data will be increasingly valuable.

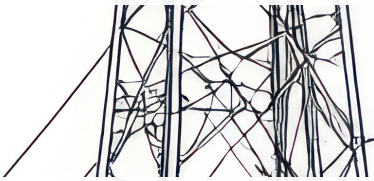
Measuring progress

Kenya's Energy Transition and Investment Plan targets net-zero emissions by 2050. Progress towards that goal should be measured by the renewable capacity installed and also by the useful energy delivered, the losses avoided, the reliability achieved and the value created for industry and communities. Improving the performance of buildings, industrial plants and energy facilities requires attention to conversion efficiency, thermal management, fluid systems, mechanical integrity and maintenance, in renewable generation as well as in the equipment and processes that use energy.

Thermodynamics explains the limits and opportunities of energy conversion. Heat and mass transfer describe how energy and materials move through systems, and fluid mechanics governs the behavior of working fluids. Mechanical design, materials selection and maintenance determine whether equipment can operate safely and reliably over its service life. These fundamentals remain central to the energy transition and to the practical solutions it requires.



> By matching renewable resources to actual demand, recovering energy where feasible, designing for local conditions and strengthening collaboration between research and industry, engineers can help Kenya make better use of every unit of energy available to it. Alongside the change in energy sources, the transition calls for more efficient conversion, better use of energy and well-integrated engineering systems.



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The Energy Within a Paper Clip: Rethinking Energy Storage



By Eng. Dr. A. A. Owayo (S. Lecturer, Moi University)

Bio summary

Eng.Dr . Alphonce Ayado Owayo is a distinguished civil engineer, academic, and researcher with over 15 years of cumulative experience in geotechnical and structural engineering. He currently serves as a Senior Lecturer in the Department of Civil and Structural Engineering at Moi University, having previously held a similar position at the Technical University of Kenya. Dr. Owayo holds a Ph.D. and MSc in Civil Engineering from the National Taiwan University of Science and Technology, as well as a BSc in Civil Engineering from the University of Nairobi. He is a registered Consulting Engineer with the Engineers Board of Kenya and has made significant contributions to research, teaching, and professional practice, including leading major engineering projects. His research interests encompass artificial intelligence applications, numerical methods in structural and geotechnical engineering, sustainable cities, advanced foundation systems, and sustainable construction materials, with a strong emphasis on resilience and innovation in civil infrastructure. Dr. Owayo has published in peer-reviewed journals, mentored numerous graduate engineers, and actively contributes to the advancement of sustainable and smart engineering solutions aligned with global sustainability goals. His vision is to advance engineering knowledge that bridges technology, sustainability, and societal impact across Africa and beyond.

ABSTRACT

A paper clip appears to be an almost trivial object: a small piece of metal weighing about one gram and costing almost nothing. Yet, viewed through the lens of Einstein's mass–energy equivalence, the same paper clip represents an astonishing quantity of energy. This raises an intriguing hypothetical question for renewable-energy and energy-storage research: could an ordinary paper clip be regarded as an extraordinarily energy-dense storage medium? The answer is both yes and no. While its mass corresponds to an enormous quantity of energy, almost all of this energy is inaccessible through ordinary physical and chemical processes. The distinction between mass–energy equivalence and usable stored energy is therefore fundamental to understanding the possibilities and limitations of future energy-storage technologies.

1. Introduction: An extraordinary battery hiding in plain sight

Imagine placing an ordinary paper clip on a laboratory balance. The balance might report approximately one gram. Nothing about the object suggests that it contains an extraordinary amount of energy. It bends, conducts electricity, corrodes, and eventually rusts. Compared to a modern lithium-ion battery, it seems completely unremarkable as an energy-storage device. But Einstein's mass-energy relationship tells us to look at the same object differently. If its entire mass could somehow be converted into energy (Eq. 1), the theoretical simplified energy equivalent would be;

$E=mc^2$ (Sathar, 2024) (1)

Where m is mass in kg, and c is the speed of light, taken as 299,792,458 m/s. For m=0.001 kg, $E=(0.001)(299,792,458)^2$ giving approximately, $E=8.99 \times 10^{13}$ J. This is approximately 2.5×10^7 kWh or about 25 million kilowatt-hours. A simple paper clip has suddenly become an extraordinary theoretical energy reservoir. But there is an important catch!

2. Energy equivalence is not the same as usable energy

Eq. 1 does not mean that every kilogram of matter is equivalent to a conventional battery containing $E=8.99 \times 10^{16}$ joules (Perkowitz and Editors, 2026) of readily extractable energy. Rather, it establishes a fundamental relationship between mass and energy. Ordinary batteries operate primarily through changes in chemical potential energy (Nasajpour-Esfahani et al., 2024; Ngoy et al., 2025). When a lithium-ion battery discharges, for

example, electrons move through an external circuit while chemical reactions occur inside the cell. The mass difference associated with the released energy technically exists, but it is extraordinarily small (Yee and Gardi, 2019). The paper clip therefore illustrates an important distinction as shown in Eq. (2):

Total mass–energy ≠ recoverable energy. (2)

The energy corresponding to the paper clip's entire mass would require a process capable of converting all of its matter essentially into another form of energy. Ordinary chemical reactions cannot accomplish this; the first law of thermodynamics (Zohuri, 2018; Mauro, 2021) tells us that energy cannot simply be created or destroyed; it can only be transformed from one form to another. Thus, although Eq. (1) predicts an enormous amount of energy associated with the mass of a paper clip, this does not mean that the energy can be readily extracted or used. The challenge lies in finding a physical process capable of converting the paper clip's rest mass into usable energy.

Quantum mechanics (Arfken et al., 1984) suggests that matter and antimatter can annihilate each other (Gato-Rivera, 2021; Omira and Mourad, 2025; Kragh, 2026). Therefore, theoretically, bringing 1 g of antimatter into contact with 1 g of paper-clip material could convert their combined mass into energy and release an enormous amount of energy (equivalent to 2 g). However, immediate complications arise from this proposition. First, obtaining antimatter is extraordinarily difficult and expensive, as it does not naturally exist in significant quantities in our everyday environment. Second, even if such a quantity of antimatter could be produced and brought into contact with the paper clip, what humanity would do with such an enormous amount of energy released within a fraction of a second remains a formidable challenge. Moreover, the resulting energy release would produce extreme heat and radiation, potentially vaporizing the surrounding materials almost instantaneously.

3. Why does burning the paper clip not fully unlock its energy potential?

Suppose the paper clip is made primarily of iron. One might ask: If iron has so much mass-energy, why can't we simply burn or chemically react it and recover that energy? The answer lies in the scale of the physical processes involved. Chemical reactions rearrange electrons and chemical bonds. The changes in mass associated with ordinary chemical energy are incredibly small (Clarke, 2008; Saleh, 2021). Nuclear processes, on the other hand, operate at a much deeper level (Murray, 1993; L'Annunziata, 2023); they involve changes in atomic nuclei and can therefore release vastly more energy per unit mass. Even nuclear reactions, however, do not normally convert 100% of matter into usable energy. Complete conversion of matter into energy is a much more extreme proposition.

4. The hypothetical perfect paper-clip battery

For the purposes of a thought experiment, however, imagine a technology capable of converting the entire mass of a one-gram paper clip into usable energy. The theoretical energy would be approximately::$E=8.99\times10^{13}$ joules as already established. That is about 25 million kWh. To appreciate the scale, consider an appliance consuming 1 kW continuously. In this completely hypothetical scenario, the paper clip's mass-energy would operate that appliance for approximately 25 million hours, or roughly 2,850 years.

This amount of energy is equivalent to approximately 21.5 kilotons of TNT, which is about 1.4 times the estimated explosive yield of the Hiroshima bomb and roughly equivalent to the yield of the Nagasaki bomb (Straume, 1995; Yale School of Law, n.d.). Further, assuming that the energy released by an earthquake can be estimated using Eq. (3).

$\log_{10} E=QM+P$ (Gutenberg and Richter, n.d.) (3)

where E is the energy, M is the magnitude of the earthquake on the Richter scale, and Q and P are constants dependent on the geological characteristics of the earthquake area. Assuming Q = 1.5 and P = 4.8 (Gutenberg and Richter, n.d.), the amount of energy released by a mere paper clip, if all its mass were converted into energy, would be approximately 42% greater than that of a magnitude 6 earthquake. For context, in 2025, a magnitude 4.5–5.0 earthquake occurred around Kilimanjaro in Tanzania, and its effects were reportedly felt in buildings around Nairobi, Kenya, a distance of nearly 300 km away (Magina, 2025; Earthquake Track, n.d.) .The paper clip would therefore possess an energy density beyond anything contemplated in conventional renewable-energy storage. Yet this is not a proposal to manufacture paper-clip batteries. It is a demonstration of how profoundly different mass-energy storage is from chemical energy storage.

5. The real challenge: energy density versus accessibility

Energy-storage technology is not simply a competition to find materials containing the most energy.The useful engineering question is: How much energy can be safely, economically and controllably extracted from a unit of material (E_{usable})? A material may have an enormous theoretical energy ($E_{theoretical}$) content but be practically useless as an energy-storage medium if the energy

cannot be accessed. This distinction can be expressed conceptually as shown in Eq (4):

$$E_{usable} = \alpha E_{theoretical} \quad (4)$$

where α represents the fraction of theoretical energy that can actually be recovered. For an idealized complete mass-to-energy converter, $\alpha=1$. For a paper clip undergoing ordinary chemical processes, however, the fraction of its mc^2 energy that is accessible is effectively negligible. Thus, the paper clip is an extraordinarily energy-dense object in the relativistic sense, but not an extraordinarily useful battery.

6. What this means for renewable energy

Renewable energy systems face a different problem (Kiplagat et al., 2011; Rotich et al., 2024). Solar and wind resources can provide enormous quantities of energy, but their output is variable. Solar power falls at night and during periods of heavy cloud, while wind generation fluctuates with atmospheric conditions. Energy storage is therefore essential for a highly renewable electricity system. Current storage technologies include:lithium-ion batteries, pumped-storage hydropower, thermal energy storage, compressed-air energy storage, hydrogen, flow batteries, and other emerging electrochemical and mechanical systems.

All of these technologies operate within the practical limits of material availability, efficiency, safety, cost, and engineering feasibility. The paper clip thought experiment offers a useful philosophical contrast. A conventional battery stores energy through relatively accessible physical or chemical mechanisms. A hypothetical mass-energy battery would store energy at an entirely different level of physics. The problem would no longer primarily be energy density. It would be how to control the conversion of matter into energy without destroying the storage device, the containment system, and everything around it.

7. The paper clip as a thought experiment in energy storage

The paper clip therefore provides an elegant way of illustrating three different meanings of stored energy. (1) Chemical energy: The paper clip can participate in chemical reactions. The associated energy is relatively small. (2) Nuclear energy: Its atomic nuclei contain energy that could, under appropriate nuclear processes, be released to a much greater extent than through ordinary chemistry. (3) Mass–energy: Its entire mass corresponds to $E=mc^2$ this is vastly greater still. These three levels should not be confused.

The fact that a paper clip has a mass–energy equivalent of approximately 90 terajoules does not mean that 90 terajoules are sitting inside it like charge inside a battery waiting for someone to connect two terminals. The equation describes a fundamental equivalence, not an engineering specification.

8. A new definition of an "Energy Store"

This thought experiment also invites a broader question. What should we call an energy-storage medium? If we define storage purely according to the amount of energy physically associated with a material, then essentially every object around us is an astonishing energy reservoir. A human body, a stone, a tree and a paper clip all have enormous mass–energy equivalents. But if we define storage according to recoverable, controllable and economically useful energy, the situation changes completely. This is the definition that matters to engineers. A battery containing 100 kWh of safely recoverable energy is vastly more useful than an object whose mass corresponds to millions of kilowatt-hours if extracting that energy is physically impractical.

9. The future: from chemical batteries to fundamental physics

Future energy-storage technologies may continue to move toward increasingly high energy densities. However, there is an enormous conceptual gap between chemical energy storage, nuclear energy and complete matter–energy conversion. The paper clip sits at the centre of this thought experiment precisely because it is so ordinary. Its small mass conceals an enormous relativistic energy equivalent. The lesson is not that paper clips are secretly revolutionary batteries. The lesson is that nature permits an extraordinary amount of energy to be associated with even tiny quantities of mass. Einstein's equation reveals an energy-storage frontier that is almost unimaginably more concentrated than conventional technologies. The engineering challenge, however, is formidable: discovering a physically possible mechanism that can access such energy while controlling the accompanying transformation of matter.

10. Conclusion

A one-gram paper clip provides a striking demonstration of the difference between energy that exists in principle and energy that can actually be harvested. Through

$E=mc^2$ its mass corresponds to approximately 9×10^{13} J or roughly 25 million kWh of mass–energy. That number is spectacular. But the paper clip is not a 25-million-kWh battery. It is instead a reminder that energy storage must always be considered in terms of accessibility, conversion efficiency, controllability, safety and practicality, rather than theoretical energy equivalence alone.

Perhaps the most profound conclusion is therefore not that enormous energy is hidden inside a paper clip. It is that the distinction between "energy contained in matter" and "energy available to an engineer" is one of the most important distinctions in thinking about the future of energy storage. The ordinary paper clip thus becomes an extraordinary thought experiment: a one-gram object that, through Einstein's equation, connects everyday engineering with the deepest relationship between matter and energy in modern physics.

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Processing and Characterization of Blowroom Cotton Fibre Waste as a Potential Reinforcement for Polymer Composites

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ABSTRACT

The increasing generation of textile waste necessitates sustainable valorization strategies that convert waste streams into value-added materials. This study investigated the processing and physicochemical characterization of blowroom cotton fiber waste (BCFW) for potential application as a reinforcement precursor in polymer composites. BCFW obtained from Rivatex East Africa Limited (Kenya) was subjected to a two-stage cleaning process using an Ele Trash Analyzer, followed by alkali treatment with 5% sodium hydroxide (NaOH). Fibre recovery, physical properties, and chemical composition were evaluated using standard analytical methods. The cleaning process achieved a fiber recovery efficiency of 79.77% with 20.23% solid impurity removal, demonstrating effective separation of reusable fiber fractions from textile waste. The recovered fibres exhibited a staple length of 2.7 cm, a short fiber content of 30.77%, and a Micronaire value of 3.52, indicating fine-to-medium fiber characteristics suitable for non-directional composite applications. Alkali treatment reduced ash content from 0.725% to 0.075% and lignin content from 10.6% to 6.32%, while increasing α-cellulose content from 94.5% to 95.8%, indicating improved fiber purity and cellulose enrichment. The combined physical and chemical characteristics demonstrate the potential of BCFW as a sustainable reinforcement material and support its valorization within circular economy-based composite applications.

Key words: blowroom cotton fiber waste; textile waste valorization; alkali treatment; composite reinforcement; circular economy.

1. Introduction

Growing environmental concerns and the need for resource-efficient materials have increased interest in natural fiber-reinforced polymer composites as sustainable alternatives to synthetic fibre systems. Natural fibers offer advantages such as low density, renewability, biodegradability, and cost-effectiveness, making them attractive for a wide range of engineering applications (Maiti et al., 2022). Their increasing adoption also aligns with circular economy principles that promote waste reduction, resource recovery, and sustainable material development.

Among natural fibers, cotton remains one of the most widely utilized due to its high cellulose content and favorable physical properties (Radoor et al., 2022; Wankhede et al., 2023). However, textile manufacturing processes generate substantial quantities of cotton waste, particularly during the blowroom stage where short fibers, neps, and impurities are removed from the raw material. This blowroom cotton fiber waste (BCFW) is commonly discarded or incinerated despite retaining significant cellulose content that could support value-added applications (Akter et al., 2024).

The valorization of BCFW into composite reinforcement materials presents an opportunity to reduce textile waste while contributing to sustainable materials development. However, limited information exists regarding the recovery efficiency, physical characteristics, and chemical composition of BCFW following industrial cleaning and treatment processes. Such information is essential for evaluating its suitability as a reinforcement precursor for polymer composite applications. Therefore, this study investigates the processing and physicochemical characterization of BCFW obtained

from textile manufacturing operations to assess its potential as a sustainable reinforcement material for polymer composites and support its utilisation within circular economy-based material systems.

2. Literature Review

Natural fiber-reinforced composites have gained considerable attention as environmentally friendly alternatives to conventional synthetic fiber composites due to their lower environmental footprint, renewability, and favorable specific properties (Maiti et al., 2022). These materials are increasingly used in semi-structural and non-structural applications such as automotive interior components, furniture, packaging, insulation panels, and building materials, where moderate mechanical performance, lightweight characteristics, and cost-effectiveness are required.

Cotton fibers have been widely investigated as reinforcement materials because of their high cellulose content, low density, biodegradability, and favorable specific properties (Radoor et al., 2022; Wankhede et al., 2023). Previous studies have shown that cotton-based composites can exhibit improved stiffness and tensile performance when adequate fiber–matrix adhesion is achieved through appropriate fiber processing and surface modification (Shetty et al., 2024). Cotton fibers are commonly incorporated into thermoplastic and thermoset matrices in short, chopped, or non-woven forms using conventional composite manufacturing techniques.

Surface modification plays a critical role in improving the performance of natural fiber composites. Among the available treatment methods, alkali treatment is one of the most widely adopted due to its effectiveness in removing waxes, lignin, hemicellulose, and other non-cellulosic constituents from fiber surfaces (Ammayappan et al., 2022). The treatment increases fiber surface roughness and accessibility, thereby improving fibre–matrix interfacial bonding and stress transfer efficiency, which are essential for effective reinforcement performance (Lakshmanan & Chakraborty, 2025).

Despite the growing body of research on natural fiber composites, most studies have focused on virgin cotton fibers or fibers derived from agricultural biomass sources. Comparatively limited attention has been given to industrial textile waste streams, particularly blowroom cotton fibre waste (BCFW), despite its potential as a low-cost and readily available reinforcement source (Ute et al., 2019). Furthermore, limited systematic information exists regarding the recovery efficiency, physical characteristics, and chemical composition of BCFW following industrial cleaning and alkali treatment. Addressing this knowledge gap is necessary for evaluating the suitability of BCFW as a sustainable reinforcement precursor and supporting its integration into circular economy-based composite applications.

3. Methods

3.1 Fiber Recovery and Treatment

The blowroom cotton fiber waste (BCFW) was sourced from the spinning department of Rivatex East Africa Limited, Eldoret, Kenya, located at approximately 0.52° North Latitude and 35.27° East Longitude. The waste material was conditioned for 24h at 21 ± 2 °C and 65 ± 2% relative humidity prior to processing. Fiber recovery was performed using an Ele Trash Analyzer MAG (SITRA, Coimbatore, India) through two successive cleaning passages selected from preliminary optimization trials. Cleaning efficiency and solid impurity removal were determined from the mass of recovered fiber and removed impurities (Ute et al., 2019).

Recovered fibers were washed and subjected to alkali treatment using a 5% (w/v) sodium hydroxide solution (Santhiarsa et al., 2023) at room temperature for 45 min. The treated fibers were neutralized with 1% acetic acid, rinsed to neutral pH, air-dried, and oven-dried at 40 °C, using an air blast oven (MF-9053A, Macro Scientific Works Pvt. Ltd., Delhi, India), before conditioning and storage for subsequent analyses. Figure 1 illustrates the processing stages of blowroom cotton fiber waste prior to its potential use as composite reinforcement.

3.2 Physical Characterization

Physical characterization included fibre staple length, fibre fineness, and visual assessment of fibre appearance. Staple length parameters, including effective length, short fibre content, and dispersion, were determined using the standard comb-sorter (array) method in accordance with IS 233 (Part 1–4):1978 (BIS, 1978) and Pita et al. (2022), using a Double Sorter apparatus (SITRA, Coimbatore, India) at the Textile Laboratory, Moi University. Fibre fineness was determined using the Micronaire method with a MAG DigiMic TX Portable Digital Micronaire Meter (Mag Solvics Pvt. Ltd., Coimbatore, India) at Rivatex East Africa Limited. Physical appearance and surface characteristics were qualitatively evaluated through visual observation and photographic documentation of untreated, cleaned, and alkali-treated fibres. Changes in colour, cleanliness, brightness, and surface texture were assessed as indicators of fibre purification and surface modification.

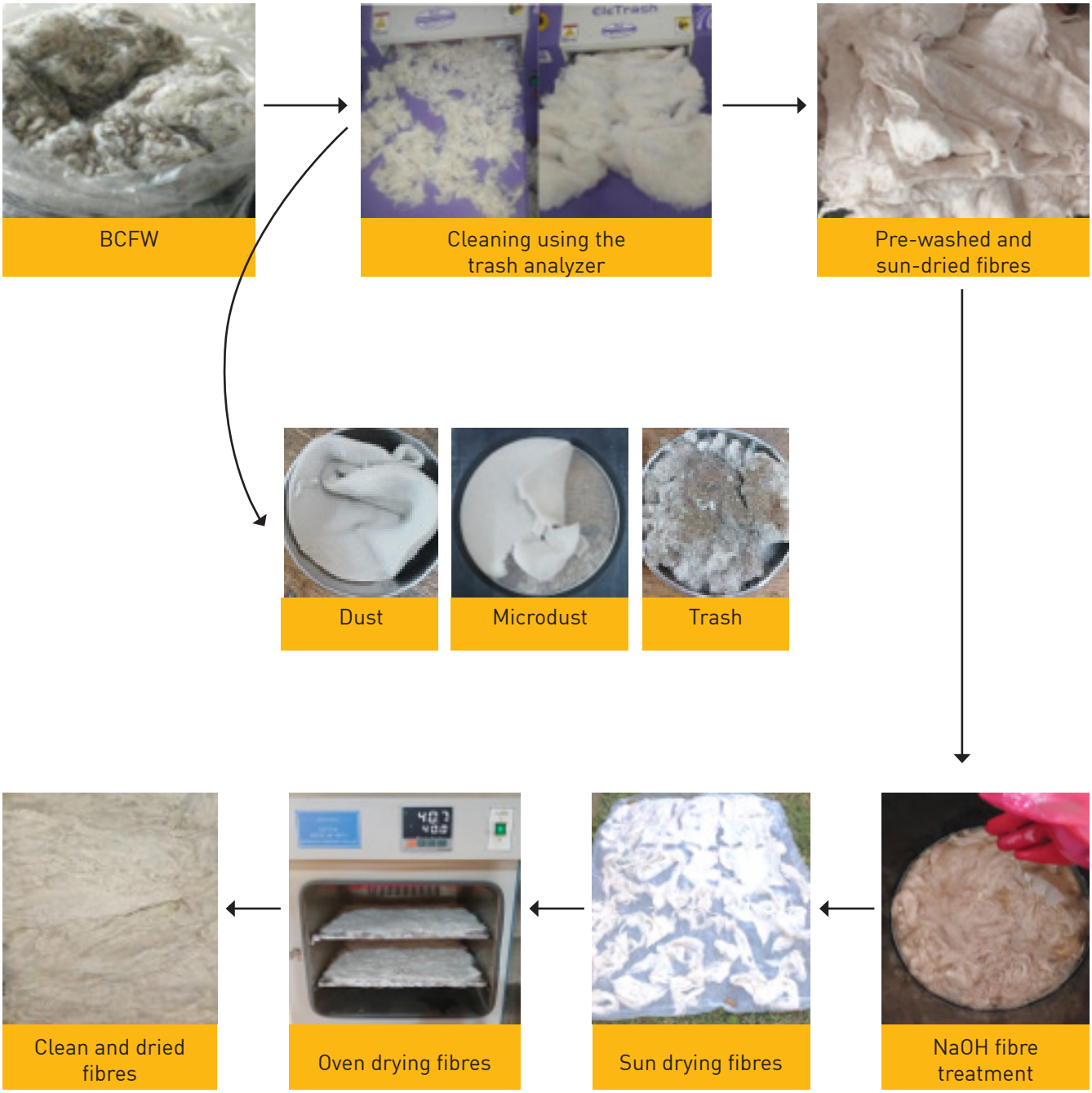


Figure 1. Processing stages of blowroom cotton fibre waste (BCFW) prior to composite reinforcement.

Source: This study.

3.3 Chemical Characterization

Chemical characterization was conducted using standard TAPPI and ASTM methods. Moisture content was determined by oven drying in accordance with TAPPI T 550 om-03, while ash content was measured by furnace combustion following TAPPI T 211 om-93. Extractive content was determined using ethanol–toluene Soxhlet extraction according to TAPPI T 204 om-97. Acid-insoluble lignin (Klason lignin) was quantified following TAPPI T 222 om-98. Holocellulose content was determined using the chlorite delignification method in accordance with ASTM D1104-56, while α-cellulose content was determined by selective alkaline extraction following ASTM D1103-60. Hemicellulose content was calculated as the difference between holocellulose and α-cellulose contents. All analyses were performed in replicate, and average values were reported (Bichang'a et al., 2023; Gonzalez et al., 2022; Hossain et al., 2025; Oluwasina et al., 2024). Figure 2 presents a schematic workflow for the chemical characterisation of the recovered cotton fibres.



Dried fibres

Oven drying at 105°C



Moisture content

600°c

Ethanol +Toluene



Ash content



Extractives

72 % Sulphuric acid

1g NaClO2 + Acetic acid

Klason lignin content





Holocellulose content

17.5% NaOH

By difference

Alpha cellulose content

Hemicellulose content

Figure 2. Sequential procedure for determining the chemical composition of cotton fibres, including the quantification of moisture, ash, extractives, lignin, holocellulose, alpha-cellulose, and hemicellulose contents.

Source: This study

4. Results and Discussion

4.1 Fibre Recovery

Based on a mass-balance calculation of the input and separated fractions (Lu et al., 2023), the cleaning process yielded a cotton lint recovery of 79.77% and a solid impurity removal (SIR) of 20.23% (Figure 3).

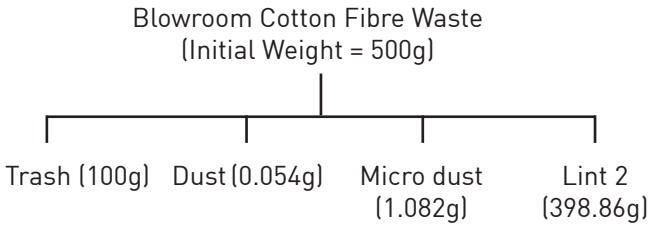


Figure 3. Blowroom cotton fibre waste (BCFW) cleaning and cotton lint recovery distribution.

Source: This study.

This level of recovery demonstrates moderate-to-high efficiency relative to reported blowroom cleaning systems, which typically range from 70–88% depending on fiber quality, machine configuration, and impurity load (Setswalo et al., 2021). Effective removal of dust, seed coat fragments, and other contaminants improves fiber surface cleanliness and reduces surface heterogeneity, thereby enhancing the potential for fiber–matrix interaction in composite applications (Amiandamhen et al., 2020; Boey et al., 2022). The recovered fibre fraction demonstrates the feasibility of recovering reusable lignocellulosic material from textile waste streams for value-added applications (Pavan et al., 2025).

4.2 Physical Properties of Recovered Fibers

4.2.1 Fiber Staple Length

The recovered fibers exhibited an effective staple length of 2.7 cm and a short fibre content of 30.77%, classifying them as short staple cotton fibers. While the relatively high proportion of short fibers may limit alignment-dependent reinforcement mechanisms, the low length variability (dispersion = 0.296%) indicates a reasonably uniform fiber-length distribution. Such uniformity promotes homogeneous fiber dispersion within polymer matrices, reducing fiber clustering and associated stress concentrations (Kandemir et al., 2020). Consequently, the recovered fibers are particularly suitable for random fibre networks such as non-woven mats and isotropic composite structures where performance depends on uniform stress distribution rather than directional strength (Thomason, 2023; Gonabadi et al., 2025; Kamourieh et al., 2024).

4.2.2 Fiber Fineness

A Micronaire value of 3.52 was obtained, placing the recovered fibers within the fine-to-medium cotton category (Basal & Dağdelen, 2019). Fiber fineness influences fiber surface area and fiber–matrix interaction, with fibers in this range generally exhibiting favorable wetting characteristics and effective interfacial bonding within polymer matrices (Wankhede et al., 2023; Long et al., 2021). The measured fineness therefore suggests potential for efficient stress transfer and reinforcement performance in composite applications, particularly in semi-structural and non-structural systems where interfacial adhesion and uniform fiber dispersion are critical (Mohammed et al., 2022).

4.2.3 Physical Appearance and Surface Characteristics

Visual assessment revealed progressive improvement in fiber cleanliness and brightness throughout the recovery process. The untreated BCFW exhibited a greyish appearance due to the presence of dust and other impurities, while cleaning and subsequent alkali treatment produced visibly cleaner and brighter fibers. The treated fibers also exhibited a slightly rougher surface texture, indicating the removal of surface impurities and non-cellulosic constituents. Such surface modification is known to enhance fiber–matrix adhesion by increasing surface accessibility and mechanical interlocking with the polymer matrix (Lakshmanan & Chakraborty, 2025). Overall, the observed changes confirm the effectiveness of the cleaning and alkali treatment processes in improving fibre quality for potential composite reinforcement applications.

4.3 Chemical Composition of Recovered Fibers

The chemical composition of untreated and alkali-treated recovered cotton fibers is presented in Table 1. Alkali treatment resulted in notable changes in fiber composition, including reductions in ash, extractives, lignin, and hemicellulose contents, accompanied by an increase in α-cellulose content. These changes indicate effective removal of non-cellulosic constituents and enrichment of the cellulose fraction.

Table 1. Comparative chemical composition of untreated and NaOH-treated recovered cotton fibers.

Source: This study.

Analysis	Chemical Composition (%)	
	Untreated Sample	Treated Sample
Moisture content	5.18 ± 1.678	6.43 ± 0.484
Ash content	0.725 ± 0.601	0.075 ± 0.035
Extractives	8.75 ± 0.420	7.3 ± 0.589
Lignin	10.6 ± 1.131	6.32 ± 0.479
Holocellulose	95.67 ± 0.722	92.37 ± 1.124
Alpha cellulose	94.5 ± 0.000	95.8
Hemicellulose	0.75 ± 0.000	Below detection limit

Moisture content increased slightly from 5.18% to 6.43% following treatment, which may be attributed to increased exposure of hydroxyl groups and enhanced fiber porosity (Manich et al., 2022). Ash content decreased substantially from 0.725% to 0.075%, indicating effective removal of inorganic residues and improved fiber purity. Similarly, extractives decreased from 8.75% to 7.30%, suggesting the removal of waxes, oils, and other surface contaminants that may interfere with fiber–matrix bonding (Lakshmanan & Chakraborty, 2025; Neuba et al., 2023).

Lignin content decreased from 10.6% to 6.32%, while hemicellulose content declined from 0.75% to below the detection limit. These reductions are characteristic of alkali treatment and indicate the removal of amorphous non-cellulosic components (Ammayappan et al., 2022). Such modifications improve fiber surface accessibility and increase the availability of cellulose-rich regions that contribute to improved fiber–matrix adhesion (Wankhede et al., 2023; Long et al., 2021).

Although holocellulose content decreased slightly from 95.67% to 92.37%, α-cellulose content increased from 94.5% to 95.8%, indicating a relative enrichment of the cellulose fraction following treatment. Increased cellulose purity is associated with improved fiber stiffness and reinforcement efficiency, which are important for composite applications requiring moderate mechanical performance (Xu et al., 2024; Dube et al., 2023; Mou et al., 2023).

Overall, the combined effects of fiber recovery, physical characteristics, and chemical modification demonstrate that the treated blowroom cotton fiber waste possesses properties suitable for reinforcement in sustainable polymer composite systems. The removal of impurities, favorable fiber fineness, relatively uniform fiber distribution, and increased cellulose purity collectively support improved fiber–matrix interaction and reinforcement potential in semi-structural and non-structural composite applications.

5. Conclusion and Future Scope

This study demonstrated the potential of blowroom cotton fiber waste (BCFW) as a sustainable reinforcement precursor for polymer composite applications. The two-stage cleaning process achieved a fiber recovery efficiency of 79.77% while removing 20.23% of solid impurities, resulting in a cleaner fibre fraction suitable for further processing.

The recovered fibers exhibited a staple length of 2.7 cm and a Micronaire value of 3.52, indicating fine-to-medium fiber characteristics with potential suitability for semi-structural and non-structural composite applications. Alkali treatment with 5% NaOH effectively reduced non-cellulosic components, including ash, extractives, lignin, and hemicellulose, while increasing the relative α-cellulose content from 94.5% to 95.8%. These changes indicate improved fiber purity and enhanced surface accessibility for potential fiber–matrix interaction.

Overall, the findings demonstrate that BCFW can be transformed from a textile waste stream into a value-added material, supporting resource efficiency and circular economy objectives within the textile and composite industries.

Future work should focus on optimizing alkali treatment parameters to establish the optimal concentration-time relationship for fiber modification and performance tuning. The findings of this study provide a foundation for further investigation into the mechanical performance of BCFW-reinforced polymer composites, which will be addressed in subsequent work. In addition, comprehensive life cycle and techno-economic analysis are recommended to evaluate scalability, environmental benefits, and industrial feasibility of the developed fibers for composite applications.

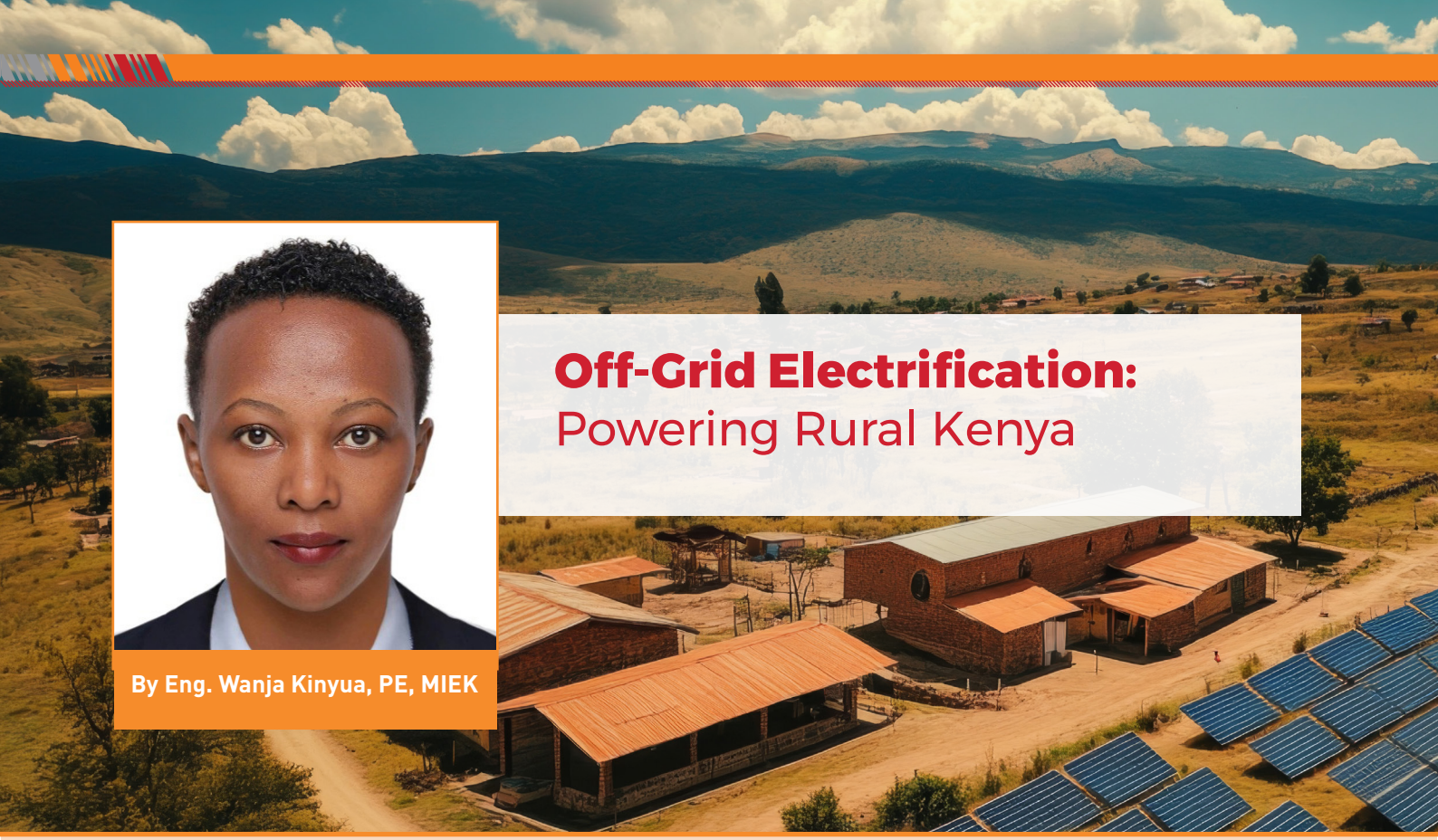
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Off-Grid Electrification: Powering Rural Kenya

By Eng. Wanja Kinyua, PE, MIEK

About 3.6 million Kenyan households still have no electricity, and many of them are too remote and too widely dispersed for the national grid to reach at a reasonable cost. Solar home systems, solar mini-grids and solar-hybridized diesel stations are now supplying a growing share of new connections. How are these systems configured and sized, and what factors determine how well they perform over their service life?

Kenya Power spends about US$6.9 million a year running diesel generators to supply Lodwar, the headquarters of Turkana County. The utility is completing a 90 km, 66 kV line from Lokichar and a 66/11 kV substation at Lodwar, at a combined cost of about US$7.8 million, to bring more than 80,000 residents onto the national grid. The case for the connection is straightforward, since its capital cost is roughly equal to one year of generator fuel.

The same reasoning does not apply to the dispersed settlements around Lodwar, or much of northern and coastal Kenya. Loads are small, households are far apart and, in pastoral areas, often mobile. For these consumers, electricity has to be generated and stored close to where it is used, and the engineering questions change accordingly.

The Access Gap

National electricity access passed 75% in 2024. About 65% of Kenyans were supplied from the national grid, 9.2% from standalone solar systems and 0.84% from mini-grids. Of 13.4 million households, 9.76 million were connected, leaving roughly 3.6 million without supply. Access stands at about 90% in urban areas and about 68% in rural areas, and the government has committed to universal access by 2030.

The Kenya Off-Grid Solar Access Project (KOSAP) addresses the hardest part of that gap. Financed by the World Bank and implemented by the Ministry of Energy and Petroleum, Kenya Power and the Rural Electrification and Renewable Energy Corporation (REREC), it targets fourteen underserved counties: West Pokot, Turkana, Marsabit, Samburu, Isiolo, Mandera, Wajir, Garissa, Tana River, Lamu, Kilifi, Kwale, Taita Taveta and Narok.

Grid extension in these counties is constrained by the ratio of network cost to energy sold. A household supplied for lighting, phone charging and a radio consumes very little energy in a month, while each kilometer of medium-voltage line, each transformer and each service connection carries a fixed capital and maintenance cost. Where demand is low and widely spread, tariff revenue cannot recover that cost. The national energy compact reflects this in its connection plan: of the 5.1 million new household connections targeted by 2030, about 199,000 are assigned to mini-grids developed by REREC and private operators.

System Types and Deployment

Off-grid supply in Kenya is being delivered at four scales. Table 1 summarizes the configuration of each and the current status of deployment.

The choice between these options depends on settlement density, load profile and the payment model. Mobile pastoral households are best served by portable solar home systems. Trading centres with commercial and agro-processing loads can justify a mini-grid with central storage. Health facilities need a dedicated supply regardless of what serves the surrounding community, because cold-chain and lighting loads cannot be interrupted.

Table 1. Off-grid system types in Kenya

System type	Typical loads	Storage	Payment model	Status in Kenya
Solar home system	Lighting, phone charging, radio, TV, sometimes a small refrigerator	Battery integrated in the household kit	Pay-as-you-go instalments by mobile money; about US$0.42 a day for a lighting kit	KOSAP target of 250,000 households; by mid-2025, 153,000 systems sold under results-based financing, reaching about 800,000 people
Solar mini-grid	Households, shops, posho mills, dispensaries and street lighting in one settlement	Central battery bank, often containerized beside the PV array	Prepaid metered tariff	113 KOSAP mini-grids in 12 counties, budgeted at about US$72.4 million; Kenya Power separately plans 80 more, worth about US$49.6 million, for about 34,000 households
Institutional system	Schools, health facilities, administration offices, borehole pumps	Dedicated battery per facility, or none for daytime pumping	Public budget	343 facility systems contracted against a target of 567; 316 solar pumps to replace diesel on community boreholes
Solar-hybrid diesel station	County towns on isolated networks	PV added to existing generating plant	National tariff	Solar retrofit of fuel-powered off-grid stations, with PV supplying daytime load and generators running after sunset; expected savings of about US$15.4 million a year

Box 1: Sizing a Village Mini-Grid

Illustrative example. (All figures in this box are assumptions chosen to demonstrate the method. They do not represent an actual site)

Consider a trading centre in an arid northern county with 150 households using 150 Wh/day each, a dispensary with a vaccine refrigerator, ten shops, a 7.5 kW posho mill operating for two hours around midday, and ten 40 W street lights operating for twelve hours each night. Figure 1 shows the assumed daily energy of each load, divided between daylight and night-time use.

Item	Parameter	Basis or formula	Value
Design inputs (assumed)			
1	Daily energy demand, E(day)	Sum of loads, Figure 1	54.3 kWh
2	Night-time demand, E(night)	Night-time share of loads, Figure 1	26.6 kWh
3	Peak sun hours, H	Arid northern site	5.5 h/day
4	Performance ratio, PR	Temperature, soiling, cable, inverter and battery losses	0.70
5	Depth of discharge, DoD	Lithium iron phosphate battery	80%
6	Inverter efficiency, η	Assumed	95%
7	Overcast reserve factor	Half a night of additional storage	1.5
PV array			
8	Required array size	E(day) ÷ (H × PR) = 54.3 ÷ (5.5 × 0.70)	14.1 kWp
9	Array specified	Rounded up	**15 kWp**
Battery storage			
10	Usable storage	E(night) × 1.5 = 26.6 × 1.5	39.9 kWh
11	Nominal capacity specified	39.9 ÷ (0.80 × 0.95) = 52.5 kWh, rounded up	**55 kWh**
Sensitivity: posho mill moved to the evening			
12	Night-time demand	26.6 + 15.0	41.6 kWh
13	Nominal capacity required	41.6 × 1.5 ÷ (0.80 × 0.95)	**82.1 kWh (+56%)**

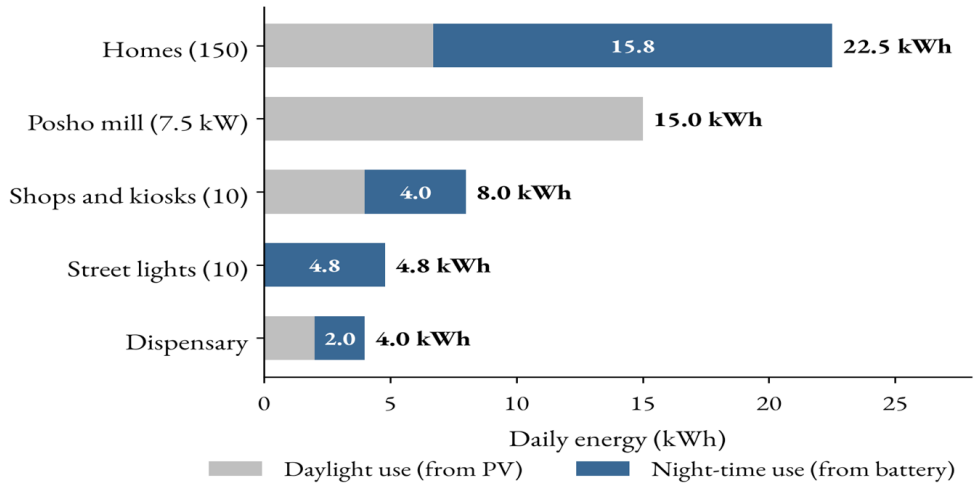


Figure 1. Assumed daily energy by load in the illustrative village. Grey shows daylight use supplied from PV; blue shows night-time use supplied from the battery, with its value in white. Totals are shown at the end of each bar.

Effect of load timing. The posho mill accounts for about 28% of daily energy but places no demand on storage, because it operates during generation hours (Item 11). Moved to the evening, the same mill raises the required battery capacity by more than 50% (Item 13). Since storage is among the highest life-cycle cost items in an off-grid system, the timing of loads is as important a design input as their magnitude. A measured load profile should therefore precede any sizing exercise.

Productive Use and Load Factor

Mini-grids that serve mainly residential lighting operate at low load factors, with consumption concentrated in the evening when energy must be drawn from storage. Revenue per installed kilowatt is correspondingly low. Daytime productive loads, such as grain milling, welding, refrigeration for milk and fish, irrigation pumping and small retail, raise the load factor and use energy directly from the array, which lowers the cost of each unit delivered.

Some operators now finance appliances alongside connections in order to build this demand. For the designer, the practical step is to agree operating windows for large motor loads with their owners at the planning stage, and to rate inverters and protection for motor starting currents.

Operation and Maintenance

Most performance problems in off-grid systems arise after commissioning, and few originate in the PV modules. Typical causes include repeated deep discharge of batteries, extended outages while inverter spares are procured, soiling of modules, meter tampering, and long response times where qualified technicians are based far from site.

The mitigating measures are well established: remote monitoring of battery state of charge and state of health, prepaid metering to secure revenue, local holding of critical spares, and trained technicians based within the service area. In May 2026, Kenya Power invited bids for single-phase prepaid meters and miniature circuit breakers to support the off-grid programme.

Community arrangements also affect asset security and revenue collection. Each KOSAP site has an allocation of about US$7,700 in corporate social responsibility funds, applied as the host community decides. During the Senate Energy Committee's review of the project in August 2026, senators raised land compensation and contractor delays, both of which bear directly on community acceptance of the sites.

Interconnection with the National Grid

As the national grid expands, it will reach some existing mini-grid sites. EPRA's draft Energy (Mini-Grid) Regulations provide for this. They apply to systems of up to 1 MW and give an operator whose network meets the Distribution Code four options on interconnection: sell power to the distribution licensee, buy bulk power from it and resell to customers, retain its own generation while also buying from the licensee, or adopt another model approved by EPRA. The distribution licensee must give at least twelve months' notice before connecting, and an operator that sells its distribution assets may negotiate compensation based on their depreciated value. When ESMAP reviewed Kenya's mini-grid sector in 2023, the regulations were still awaiting gazettement, and EPRA's 2017 mini-grid guidelines remained in use.

Designers can reduce the cost of eventual interconnection by building to utility standards from the outset, using standard distribution voltages, line construction to Kenya Power specifications and revenue-grade metering. A mini-grid built in this way can be absorbed into the distribution network on interconnection, rather than decommissioned.

Battery End of Life

Battery replacement is a major recurring cost in off-grid systems and their main source of hazardous waste. By mid-2025, 153,000 solar home systems had been sold

under KOSAP's results-based financing component, in addition to the central battery banks in mini-grids and institutional systems. All of these batteries will eventually need replacement, many of them in counties with no recycling capacity.

Product quality is the first control. In 2021, Kenya adopted KS IEC/TS 62257-9-8:2020 as a mandatory quality standard for stand-alone renewable energy products rated at up to 350 W, a category that covers most household kits. Collection and recycling are the second control. Take-back obligations, collection points in county towns and the use of licensed recyclers should be specified in procurement contracts from the start.

Implications for Practice

Off-grid systems are small, but the consequences of poor engineering are immediate. An isolated system has no network to fall back on, and errors in sizing or protection are felt directly by the consumers it supplies. Five practices follow from the issues discussed:

1. Base system sizing on a measured load profile, including the time of use of each major load.
2. Schedule productive loads within generation hours and size storage for the remaining night-time demand.
3. Design to utility distribution standards so that the system can later be connected to the national network without rebuilding.
4. Verify protection, earthing and battery management settings during field commissioning, not only at factory acceptance.
5. Include spares, monitoring, local maintenance capacity and battery recovery in the contract scope.

Grid extension will continue to deliver most new connections in Kenya. For the most remote households, however, the first reliable supply will come from solar generation and storage located within their own community, and whether that supply is still available ten or fifteen years after commissioning will depend largely on decisions made at the design and contracting stage.

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PICTORIAL REPORTS



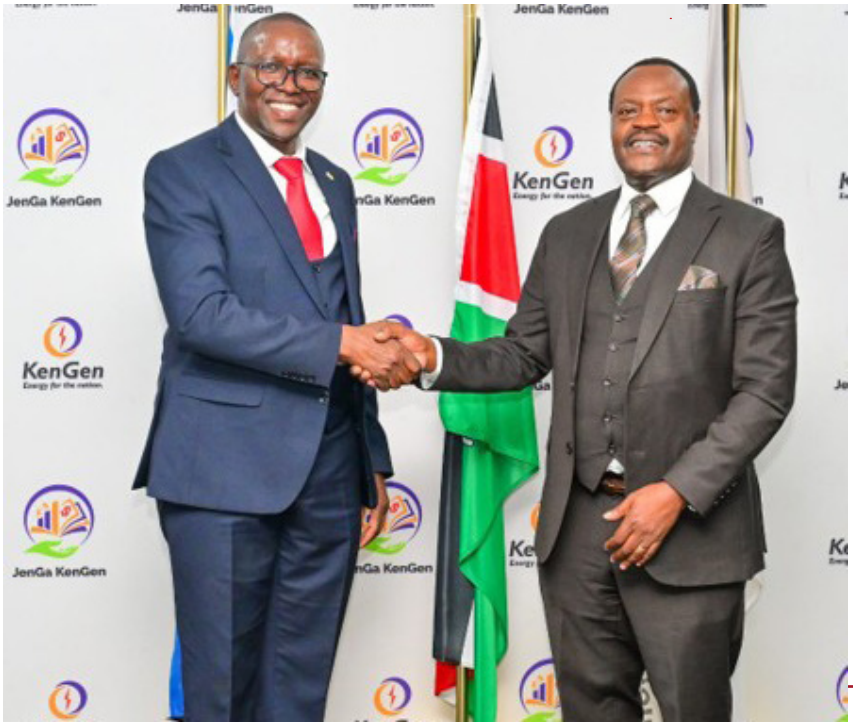
From left: Eng. Dr. Damaris Oyaro (Council Member, IEK), Eng. Otieno Ogallo (2nd Vice President, IEK), Eng. Harrison Keter (President, IEK), Eng. Joseph Siror (Managing Director, Kenya Power), Eng. Grace Muthoni Kagondu (Honorary Secretary, IEK), Eng. Radiance Mungu (Council Member, IEK), Eng. Paul Ocholla, and Eng. Nashon Tambo (Council Member, IEK). The IEK delegation paid a courtesy call to Kenya Power to explore areas of mutual cooperation.



IEK President Eng. Harrison Keter has over a copy of the Engineering in Kenya (EiK) Magazine Energy edition to Kenya Power Managing Director Eng. Joseph Siror, after concluding discussions on potential areas of collaboration between IEK and Kenya Power



From left: IEK 2nd Vice President Eng. John Robert Otieno Ogallo, Principal Secretary, State Department of Roads, Eng. Joseph Mbugua, and IEK President Eng. Harrison Keter. IEK leadership met with the PS to discuss issues concerning engineers and the upcoming 33rd IEK International Convention.



IEK President Eng. Harrison Keter with Eng. Julius Odumbe, General Manager, Operations, KenGen.IEK leadership paid a courtesy visit to KenGen at Stima Plaza Business Centre to strenghten IEK-industry collaboration



IEK Honorary Secretary, Eng. Grace Muthoni Kagondu and Athi Water Works Development Agency (AWWDA) CEO Eng. Joseph Kamau. IEK delegation paid a courtesy call to AWWDA headquarters and held discussions on strengthening partnerships in the water sector.



IEK President, Eng. Harrison Keter with Actom Kenya Managing Director Eng. Kelvin Oriwo. The Actom Kenya delegation paid a courtesy visit to IEK at Top Plaza to discuss Engineering, Industry & Innovation Partnerships.



From left: Eng. Otieno Ogallo (2nd Vice President, IEK), Eng. Nicholas Airo (Managing Director, NAS Group), Eng. Harrison Keter (President, IEK) and Eng. Grace Muthoni Kagondu (Honorary Secretary, IEK). The IEK delegation paid a courtesy call to NAS Group to explore areas of collaboration and mutual interest and the upcoming 33rd IEK International Convention



IEK Council Member, Eng. Dr. Damaris Oyaro and IEK President Eng. Harrison Keter with IMEXOLUTIONS Managing Director Mr. Shinu Vattathara together with staff from IMEXOLUTIONS. IEK delegation paid a courtesy call to IMEXOLUTIONS to discuss potential areas of collaboration and partnerships.



Eng. James Karori (Council Member, IEK) and Eng. Harrison Keter (President IEK) together with Prof. Gong Ke, Chair of the WFEO Engineering Capacity Building for Africa Programme (ECBAP). They met on the sidelines of the



NaMATA Director-General Eng. Francis Gitau (front, right) hosts an IEK delegation led by President Eng. Harrison Keter (front, centre), 2nd Vice President Eng. Otieno Ogallo (front, left) and Capital Branch Chair Eng. Radiance Mungu (back, centre) alongside officials from NaMata.



IEK President, Eng. Harrison Keter with Kenya Civil Aviation Authority Acting Managing Director, Nicholas Bodo HSC at KCAA headquarters. IEK president paid a courtesy visit to KCAA to discuss issues affecting engineers in aviation, the upcoming 33rd IEK International Convention and promoting engineering excellence in aviation.



Representatives from the Institution of Engineers of Kenya (IEK), including Dr. Eng. Damaris Kerubo Oyaro, Eng. Desmond Barongo Nyagwoka, and Eng. Nashon Tambo, pose with NIA Chief Executive Officer Eng. Charles M. Muasya, MBS and NIA staff following a consultative meeting at Irrigation House. IEK held discussions to discuss collaboration and partnership opportunities



IEK Council Members Eng. Dr. Damaris Kerubo Oyaro and Eng. Yvone Robert pose for a photo at the conclusion of a mentorship session with engineering students from Machakos University. The students were mentored on what to expect after graduation, potential career paths and further educational opportunities.



Institution of Engineers of Kenya (IEK) led by Eng. Grace Kagondu (Honorary Secretary), Council Members Eng. Dr. Damaris Oyaro, Eng. Yvone Robert, and Eng. Desmond Barongo, alongside Eng. Paul Ochola (Technical Papers Committee)—pose with delegates from EBK, ACEK, ISK, and Sika Kenya during a collaborative meeting on technical capacity development at Sika Headquarters.



From left: Naomi Kones (Membership Officer, IEK Secretariat), Alvine Wasonga (Business Development Manager-Power Techniques, Atlas Copco), Eng. Maureen Auka (CEO, IEK Secretariat), Raphael Kiandiko (CEO, Atlas Copco Eastern Africa), Eng. Yvone Robert (Council Member, IEK), Eng. Dr. Damaris Oyaro (Council Member, IEK) and Alvin Lugalia (Business Development Manager, Atlas Copco)



Eng. Otieno Ogallo (2nd Vice President, IEK) presenting a gift to Prof. Hussein Golicha (Deputy Vice Chancellor Academic and Student Affairs, Masinde Muliro University of Science and Technology). Eng. Ogallo together with an IEK delegation from Future Leaders Committee paid a courtesy visit to the DVC MMUST to discuss potential areas of collaboration between IEK and MMUST



IEK President Eng. Harrison Keter at KBC Channel 1 to discuss national infrastructure developments in Kenya and the upcoming 33rd IEK International Convention



Group Photo: IEK Future Leaders Committee pose for a group photo together with engineering students from Masinde Muliro University after a mentorship session. The mentorship session was done in collaboration with the Association of Consulting Engineers Future Leaders (ACEK Future Leaders) and the Engineering Board of Kenya on 16th September 2026



From left: Grace Wanjihia (Membership and Training Manager, IEK Secretariat), Eng. Grace Onyango (Acting Registrar, Engineers Board of Kenya), Eng. Grace Kagondu (Honorary Secretary, IEK) and Eng. Maureen Auka (CEO, IEK Secretariat). The IEK delegation paid a courtesy visit to the Engineers Board of Kenya (EBK) to discuss the upcoming 33rd IEK International Convention.

Efficient Utilization of Geothermal Resource Through Simulation of a Binary Power Plant Using Brine From 105mw Project in Menengai Geothermal Field, Kenya.

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ABSTRACT

Geothermal Development Company (GDC) has achieved significant milestones through the Menengai 105 MW Geothermal Project, where it supplies steam to three Independent Power Producers (IPPs). These IPPs are currently generating electricity and supplying power to Kenya's national grid, contributing to the country's energy security and renewable energy goals

This project has resulted in the production of approximately 1,000 t/hr. of geothermal brine at an estimated pressure of 6 bar and corresponding temperature of 158°C. To enhance the overall utilization efficiency of the geothermal resource, this study investigates the potential of converting half 250t/hr. of the produced brine into additional power through a binary cycle power plant simulation. The objective is to generate additional electrical power, thereby increasing GDC's revenue while ensuring sufficient fluid reinjection to maintain reservoir sustainability.

Thermodynamic simulations were carried out using Engineering Equation Solver (EES) software to analyze the performance of a binary plant system. Optimization of the cycle was achieved by examining the influence of key parameters, including working fluid selection and component performance on the overall system efficiency. The findings show that using R245fa as the working fluid and a brine discharge temperature of 100°C, a net power output of 2,247 kW and an overall thermal efficiency of 12.88% can be realized.

Key words: Binary Power Plant, Heat Exchanger, Working Fluid

1. INTRODUCTION

Kenya's electricity generation from geothermal has been predominantly through conventional flash power technology with a few binary plants units. Recently there has been a considerable shift to development of binary power plant units-a case study of Menengai geothermal field where two IPPs each generating 35 MW using modular ORC units. The availability of geothermal fluids (brine) from 105 MW Menengai project makes it suitable candidate for binary power plant technology. This is to ensure both geothermal resources and huge capital investments incurred during drilling are optimally utilized. One of the methods to achieve optimization of geothermal resource is the use of Organic Rankine Cycle (ORC) technology. ORCs operate over a narrow temperature range between the geothermal resource temperature and the ambient temperature, as a result, the thermal efficiency that is the ratio of the net power generated to the rate of heat input is quite low compared to conventional steam plants. Whereas thermal efficiencies of 35-40 % are easily achieved in conventional plants, geothermal binary plants typically have efficiencies in the range of 5-15 %, and are strongly influenced by the resource and the ambient temperatures, especially the latter. This study therefore analyses all the stages of a Binary Plant Cycle to identify components and parameters of the geothermal fluids and type of working fluid that contribute to thermal efficiencies of a Binary Plant Unit. The project involve simulation using Engineering Equation Solver and the results will inform possible options to adopt to achieve optimal net power and reasonable thermal efficiency.

1.1 Parameters of Geothermal Fluids (Brine)

Geothermal fluids analyzed in this study were sourced from Menengai geothermal filed where first phase development of 105MW is at advanced stage. The fluids were obtained from main reinjection line hence predominantly liquid-

dominated although they retain a significant amount of energy that can be effectively harnessed through a binary power plant. It was worth to note that enthalpy of the fluids is 666.8 kJ/kg hence the brine flow rate of 250 t/hr. has lower energy compared to pure steam which result in lower power output.

Thermophysical properties of geothermal brine used in the simulation are summarized in table 1.

Table 1: Thermophysical properties of geothermal brine

Parameters of Geothermal Fluid (Brine)	
Mass Flow Rate	250 t/hr.
Pressure	6 bar
Temperature	158°C
Enthalpy	666.8 kJ/kg
Entropy	1.923 KJ/Kg-K
Type	Liquid dominated

One of the major operational challenges in the Menengai geothermal field is silica scaling, which occurs due to the precipitation of amorphous silica as the brine cools. This can lead to reduced permeability in reinjection wells and increased maintenance requirements.

To mitigate silica scaling, the brine discharge temperature was carefully controlled and set at 100°C, which is above the silica saturation threshold for brine intended for reinjection into well MW-02. Maintaining the brine at this temperature ensures that silica remains in solution, thereby minimizing deposition risks. The relationship between temperature and silica saturation is illustrated in Figure 1, which presents the amorphous silica saturation curves for the brine used in the simulation.

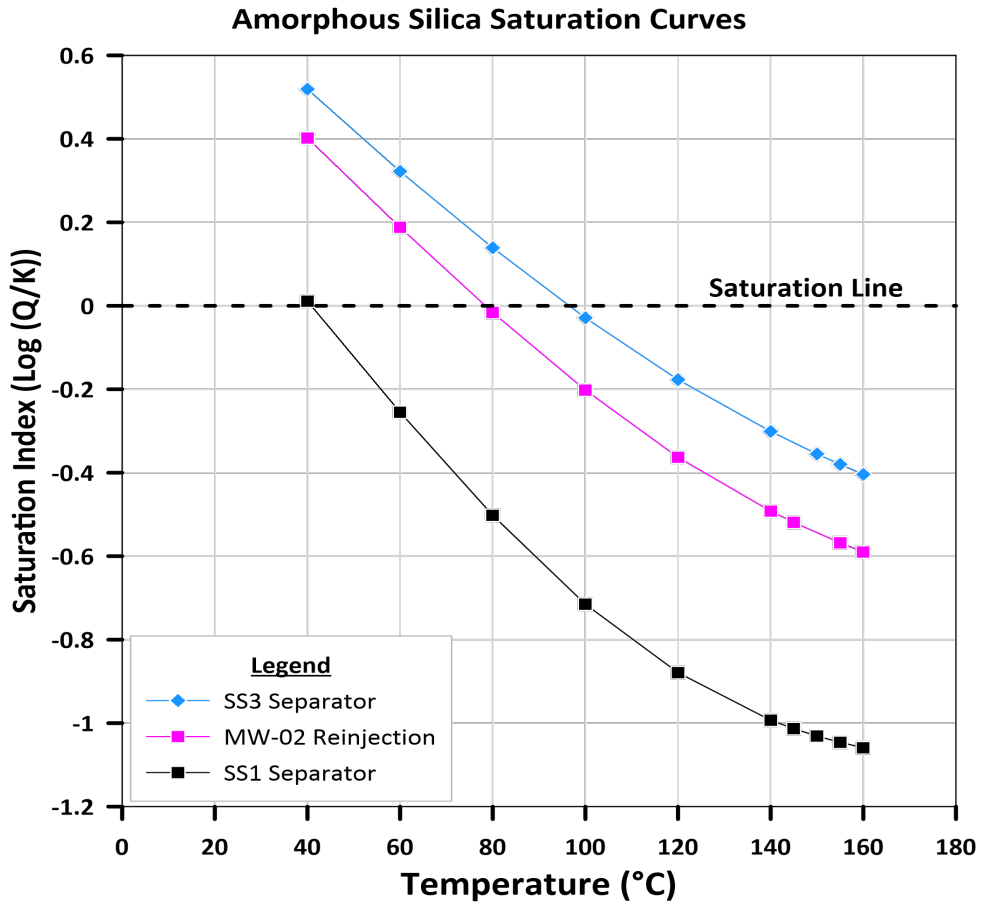


Figure 1: Amophours Silica Saturation Curves. (GDC, 2025)

2. WORKING FLUID, HEAT EXCHANGE AND OPTIMIZATION

2.1 Selection of the Working Fluid

The choice of a working fluid significantly influences the performance of a binary plant. Although many choices for working fluids are available, the selection is constrained by the thermodynamic properties of the fluids as well as considerations of health, safety, and environmrntal impact. The selection of the working fluid was mainly based on the available geothermal fluid characteristics.

There are three types of working fluids, i.e. dry fluids, wet fluids and isentropic fluids. A dry fluid has a positive slope of the saturation curve on a T-S diagram; a wet fluid has a negative slope; and an isentropic fluid has an infinitely large slope. Generally, dry and isentropic fluids are better working fluids for power plants based on organic Rankine cycle because they do not condensate after the fluid goes through the turbine. Figure 2 shows types a comparison of working fluids.

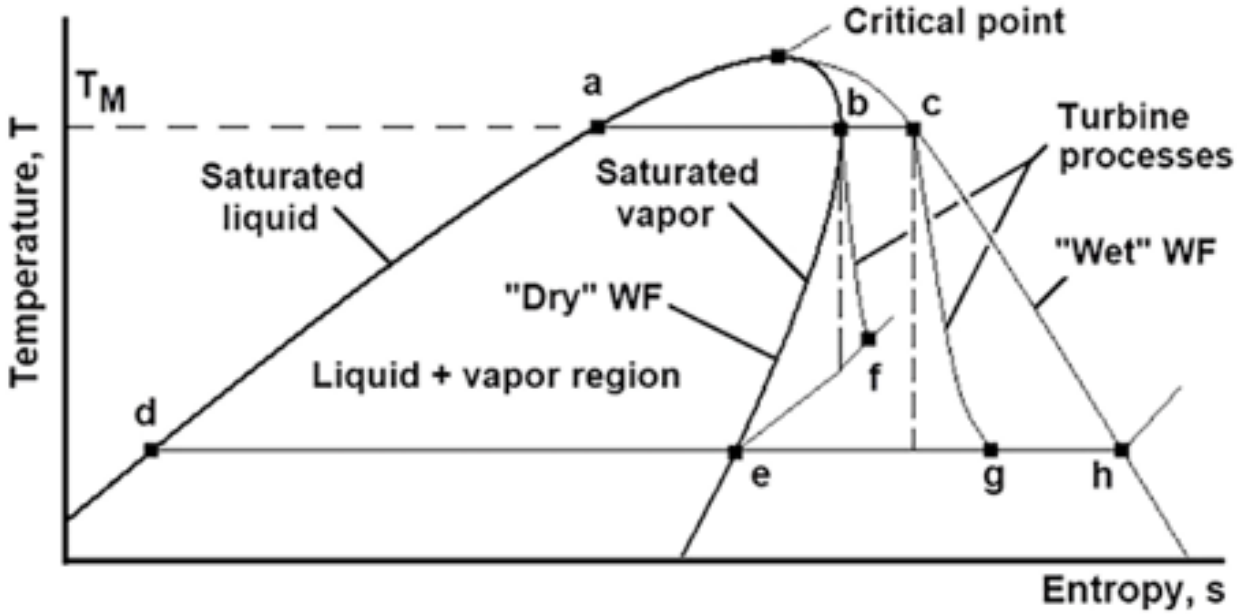


Figure 2: "Wet" and "Dry" fluids compared, modified from DiPippo (2016).

Binary mixtures of these fluids have been studied for use in geothermal binary plants. Mixtures evaporate and condense at variable temperature, unlike pure fluids that change phase at constant temperature. This means that subcritical-pressure boilers for mixed fluids can be better matched to the brine curves, in a manner similar to, but not exactly like supercritical pure fluids.

Different working fluids portray varying characteristics with similar geothermal fluids. Working fluids play an integral part in efficiency and net power output of a binary plant. For this reason, different working fluids were simulated through the pre-heater, evaporator, turbine, condenser and the feed pump. Optimal operational conditions were then determined through this analysis.

Table 2: Thermodynamic properties of some candidate working fluids for binary plants

Fluid	Formula	Tc (°C)	Pc (MPa)
Propane	C_3H_8	96.95	4.236
i-Butane	i-C_4H_{10}	135.92	3.685
Butane	C_4H_{10}	150.8	3.718
i-Pentane	i-C_5H_{12}	187.8	3.409
n-Pentane	C_5H_{12}	193.9	3.240
Ammonia	NH_3	133.65	11.627
Water	H_2O	374.14	22.089
R-245fa	$C_3H_3F_5$	154.01	3.651

To obtain good thermal efficiencies of geothermal power generation, the turbine exhaust pressure must be as low as can be economically achieved with the available cooling water or air temperature. Figure 3 shows saturation pressures versus temperature for some common fluids in geothermal power plants.

Using the example organic working fluids of ammonia, isobutene, propane, R134a or R245fa have condensing pressure near or well above atmospheric at typical environment temperatures. Thus, air leakage into these systems should not be a problem. It should be noted that the thermodynamic properties of many organic working fluids in binary power plants are such that the turbine exhaust state of the fluids remains in the superheated region. This generally is not the case with geothermal steam turbines.

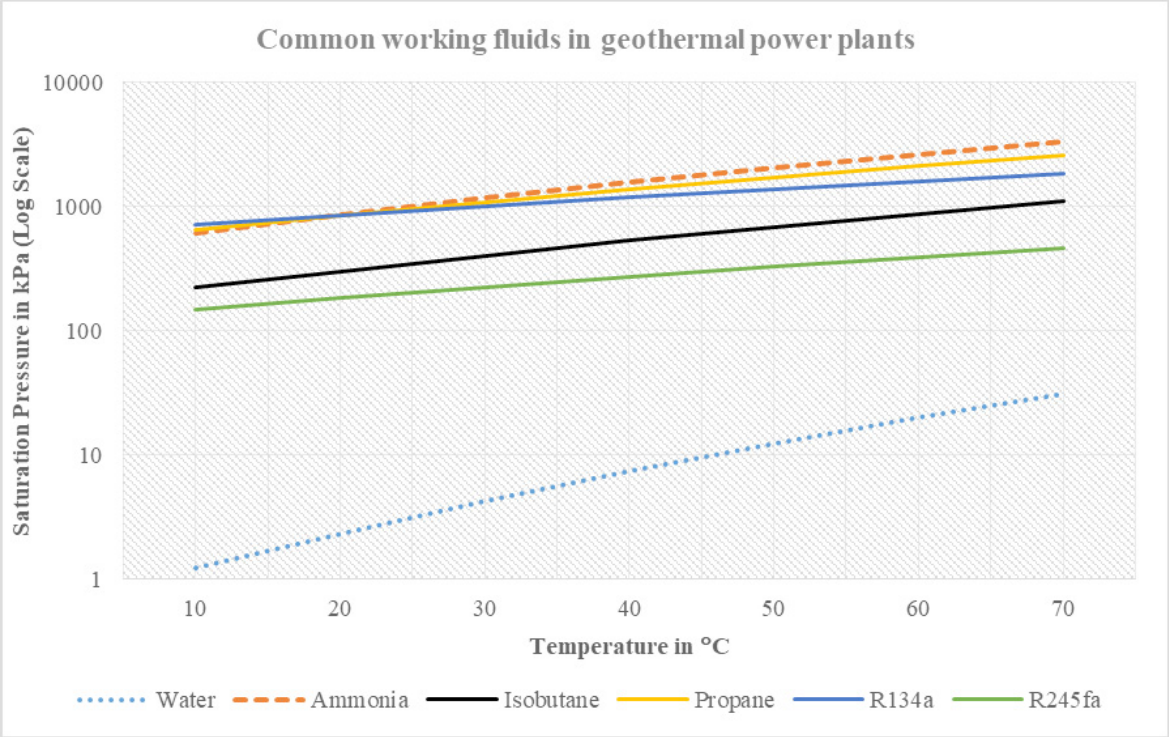


Figure 3: Saturation pressure of WF under varying condenser temperatures

From the analysis of the working fluids, butane and R245fa have their critical temperatures at 150.8°C and 154.01respectively. These temperatures closely match with the resource temperature and this is the primary criteria for choosing a working fluid. It was noted that R245fa displayed the best thermal efficiency 0f 12.88% followed by isobutane with a thermal efficiency of 10.31% under same conditions. Therefore R245fa was chosen as the working fluid for this study. Figure 4 shows T-s diagram of R245fa.

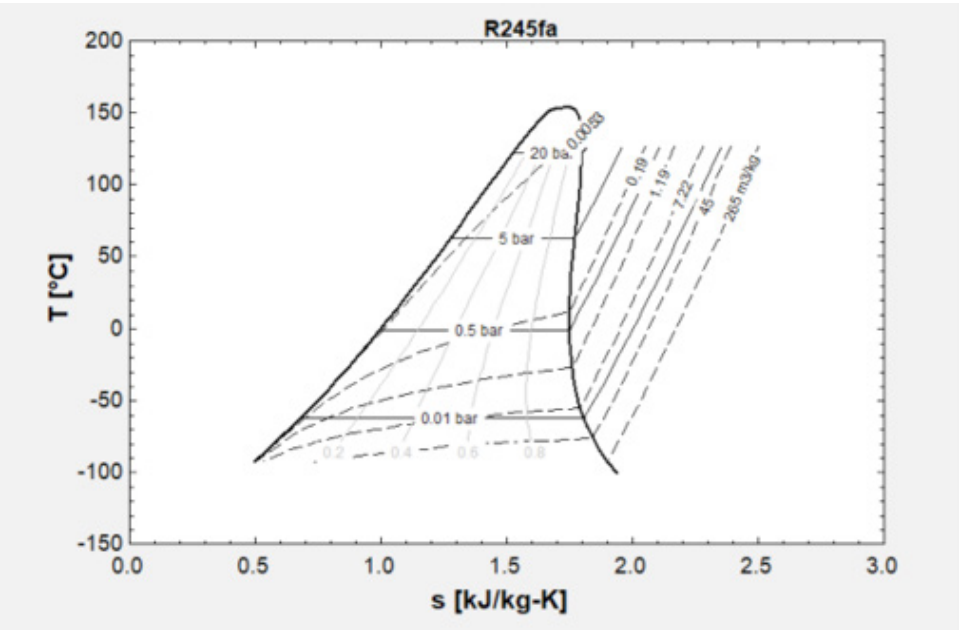


Figure 4: T-S Diagram Of R245fa

2.2 Heat Exchanger- Preheater And Evaporator

Heat exchange between geothermal brine and working fluid is key in the performance of a Binary Power Plant unit. T- q diagram illustrates the heat transfer interaction between geothermal brine and the working fluid within the preheater and evaporator of a binary cycle power plant. The geothermal brine releases heat as its temperature decreases, while the working fluid absorbs heat through sensible heating and phase change processes. The pinch point temperature difference represents the minimum temperature difference between the two fluids and governs the effectiveness of heat transfer and overall cycle efficiency. Figure 5 shows T-q diagram.

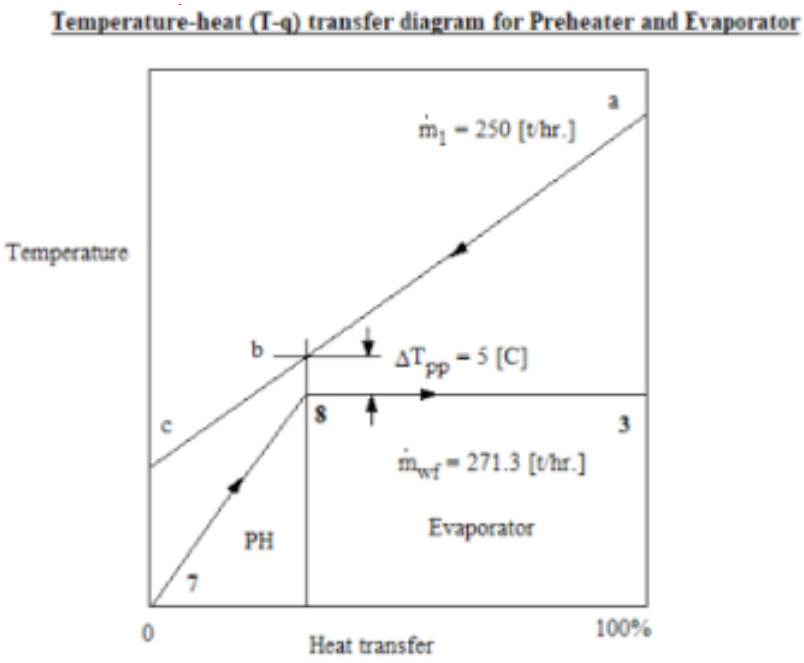


Figure 5: T-q diagram

From the EES simulation, it was noted that geothermal fluids flow rate of 250 t/hr. requires 271.3 t.hr. of the working fluid. A pinch point of 5° was chosen for simulation. A smaller pinch point temperature difference enhances heat recovery and reduces exergy destruction, thereby improving net power output. Proper matching of working fluid thermophysical properties with the geothermal brine temperature profile is therefore essential for optimal binary cycle performance. Working fluids such as R245fa provide favorable temperature matching and efficient heat transfer characteristics, making them suitable for medium-temperature geothermal power generation.

An investigation of the resource temperature of 158°C and a discharge temperature was carried out to set the optimal operating conditions. Discharge temperature was varied from 80°C to 125°C to evaluate its influence on heat recovery depth, heat exchanger exergy destruction, turbine power output, and overall exergy efficiency. Figure 6 shows brine discharge temperature versus exergy.

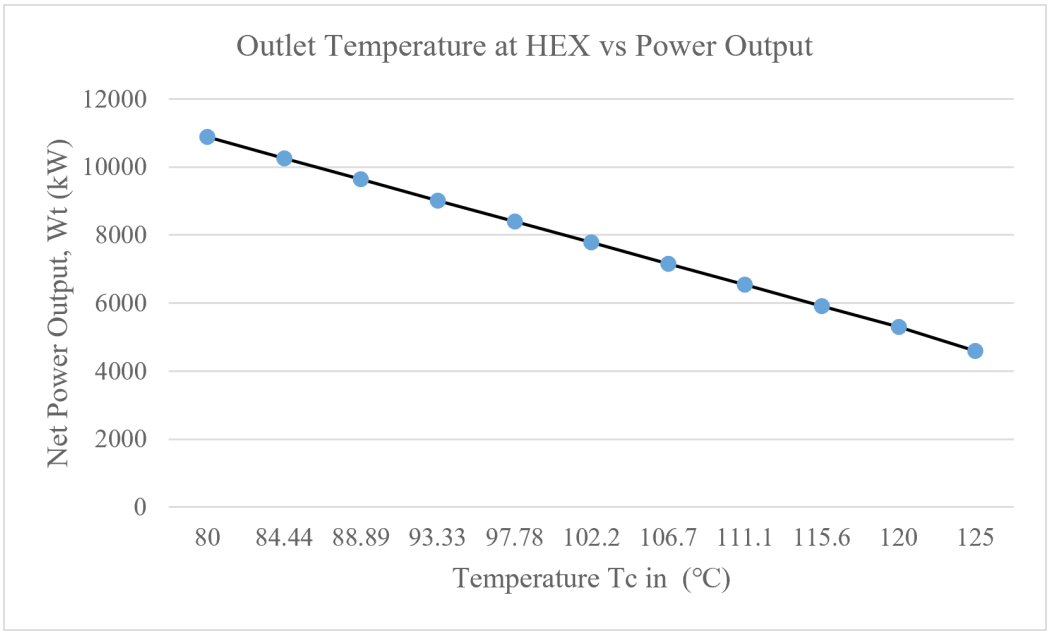


Figure 6: Brine discharge temperature versus exergy.

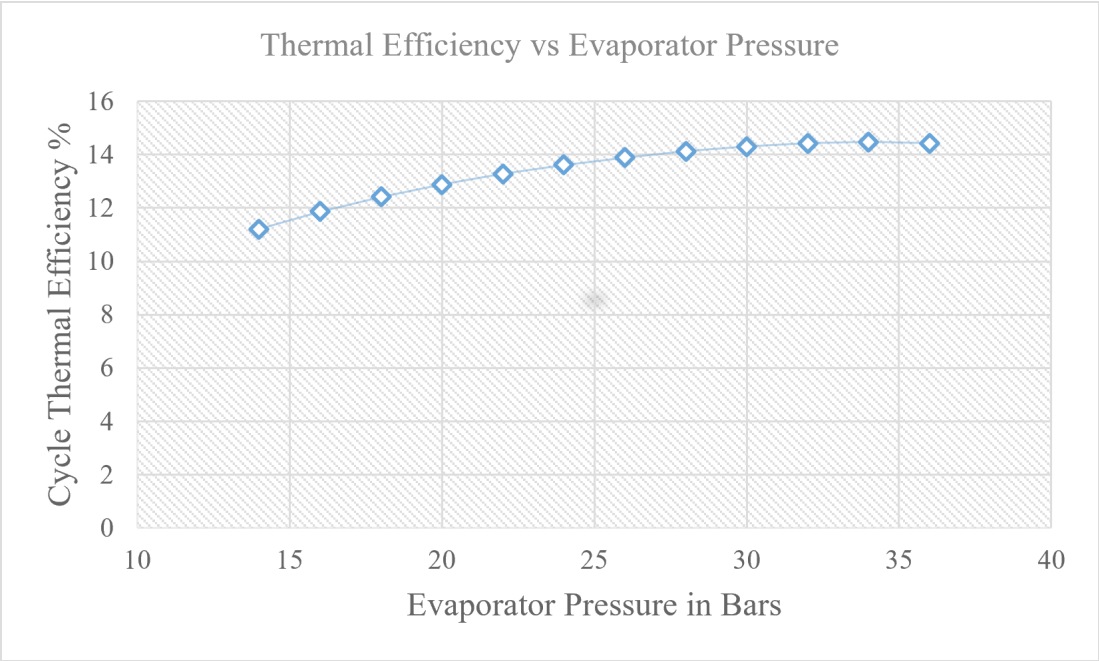
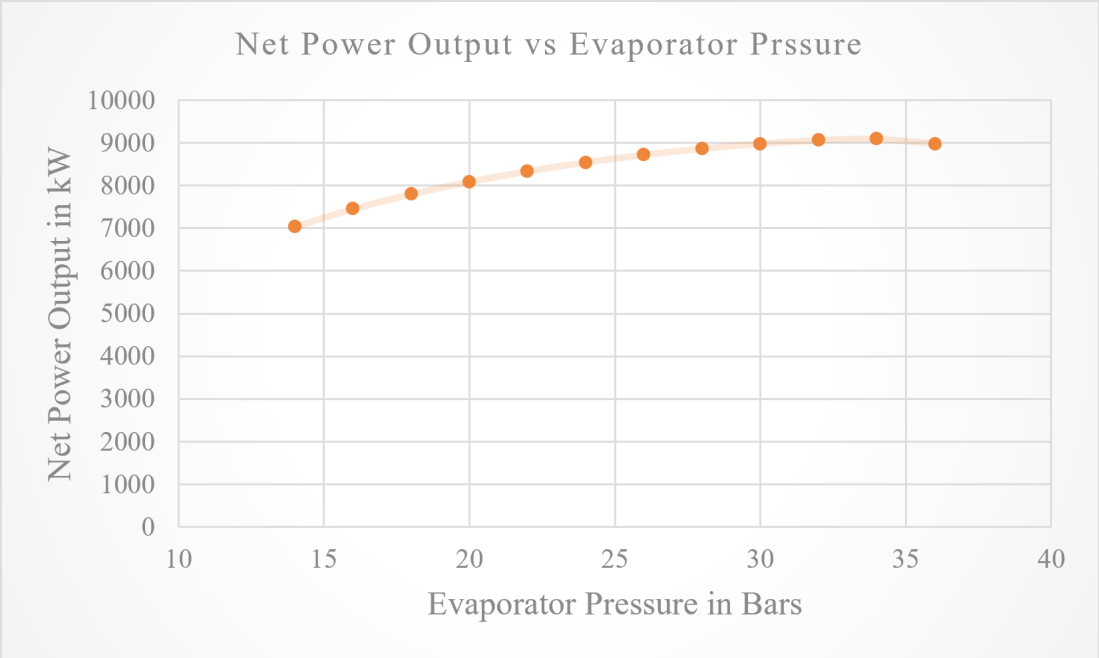


Figure 7-a: Net power output versus evaporator pressure

Figure 7-b: Net power output versus



evaporator/turbine pressure

3. SUMMARIZED RESULTS

Using Engineering Equation Solver, the geothermal resource parameters and R245fa as the working fluid, figure 9 shows the results which were obtained in the cycle analysis.

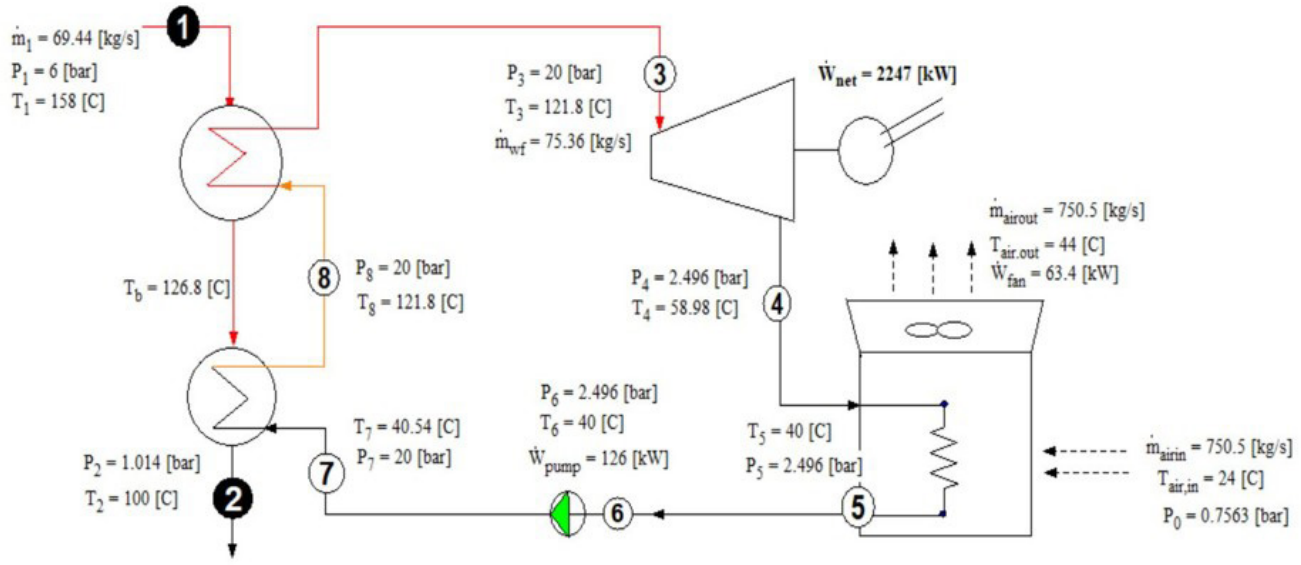


Figure 8: Binary Power Plant Cycle

4. DISCUSSION

The optimization of geothermal resource through a binary power plant in this study entailed analysis of the geothermal resource characteristics, thermodynamic cycle analysis and performance evaluation of key system components. The geothermal fluids for this simulation was sourced from main reinjection line to MW-02 with a mass flow rate of 250 t/hr., 158°C and 6 bar.

It was noted that discharge temperature from the heat exchanger (preheater and evaporator) has a huge impact on the cycle thermal efficiency and net power output. Variations of the discharge temperature was done with a close consideration on the silica saturation temperature of the combined fluids. Lower discharge temperature increases the extracted exergy portion of the geothermal resource. From a thermodynamic perspective, the optimal discharge temperature corresponds to the minimum allowable outlet temperature within operational constraints. Since exergy destruction decreases and power output increases monotonically across the investigated range, discharge temperature of 80°C provided the highest second-law efficiency and maximum net power generation. However to mitigate silica saturation during reinjection, 100°C was chosen as a practical operational discharge temperature.

Selection of the suitable working fluid entailed analysis of their thermodynamic properties as well as considerations of health, safety and environmental impact. R245fa emerged as the best option for the simulation.

Optimum simulation results through Engineering Equation Solver (EES) gave net power output of 2,247 kWe with a corresponding cycle thermal efficiency of 12.88%. Summarized results of the EES simulation are tabulated in table 3.

Table 3: Summarized Optimized Results

Optimized for best thermal efficiency and power	
R245fa mass flow rate, kg/s	75.36
GF mass flow rate, kg/s	69.44
Turbine pressure, MPa	2.0
Total heat input, kWt	17438
Turbine power output, kW	2436
Generator Power output, kWe	2247
Pump work input, kWe	126
ACC fan motor input, kWe	63.4
Parasitic load, kWe	189.4
Plant thermal efficiency, %	12.88
GF discharge temperature,°C	100

Values in table 3 are consistent with typical performance ranges for medium-temperature geothermal binary plants, confirming the validity of the design approach. The results also highlight the importance of integrated optimization, where resource characteristics, working fluid selection, and operating parameters are simultaneously considered to achieve maximum efficiency.

5. CONCLUSION

This study successfully achieved its objective of optimization of geothermal resources by simulating a binary cycle power plant using detailed thermodynamic modelling. The evaluation of geothermal brine parameters from 105MWe project in Menengai field confirmed that medium-temperature resources can be effectively utilized for power generation through ORC technology.

The analysis demonstrated that brine discharge temperature is a critical parameter affecting both energy recovery and operational reliability. While lower discharge temperatures improve exergy utilization, silica scaling imposes a practical lower limit. An optimal discharge temperature of 100 °C was therefore identified as a realistic compromise between thermodynamic performance and operational constraints.

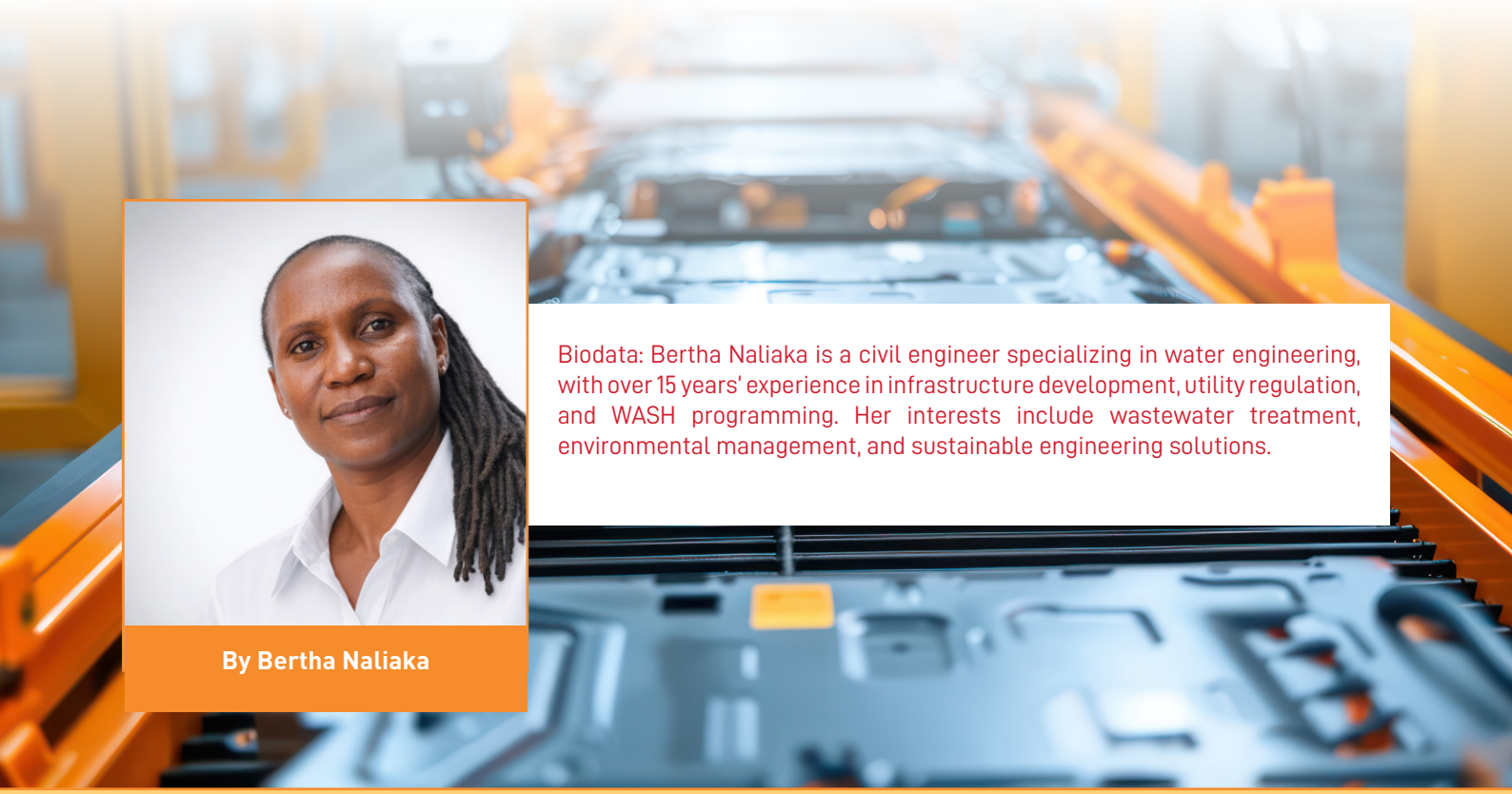
The study further established that working fluid selection significantly influences system performance. Among the fluids evaluated, R245fa emerged as the most suitable due to its favorable thermodynamic characteristics. Optimal operating conditions were identified at a pressure of 2.0 MPa and a working fluid flow rate of 271.3 t/hr. (75.36 kg/s).Under these conditions, the plant achieved a net power output of 2,247 kWe and a thermal efficiency of 12.88%, which is consistent with standard performance ranges for binary geothermal systems operating on medium-temperature resources. Therefore, it is viable to set up a binary power plant unit using brine from 105MWe Project.

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From Importer to Innovator: Building Kenya's Renewable Energy Industry



By Bertha Naliaka

Biodata: Bertha Naliaka is a civil engineer specializing in water engineering, with over 15 years' experience in infrastructure development, utility regulation, and WASH programming. Her interests include wastewater treatment, environmental management, and sustainable engineering solutions.

Kenya has made impressive progress in renewable energy. Geothermal plants at Olkaria, wind farms, and solar installations have expanded access to clean electricity and strengthened our energy supply. However, much of the equipment behind this progress still comes from abroad. We have become increasingly capable of using renewable energy technologies, but there is more work to be done in designing and manufacturing them ourselves.

This is an opportunity worth taking seriously. Kenyan engineers already design solar systems, install equipment, integrate electrical components, and keep projects running. The next step is to use that experience to develop products that local companies can manufacture, test, and improve. Doing so would create opportunities for engineering firms, technical institutions, and young professionals, while helping more of the value generated by the energy transition remain in Kenya.

The figures provide useful starting points. Sustainable Energy for All (SEforALL), in its *Kenya Green Manufacturing Policy and Investment Guide (2025)*, highlights the opportunities for Kenya to develop domestic manufacturing in green technology value chains. Simultaneously, the Kenya National Bureau of Statistics (KNBS) reported that manufacturing's share of GDP declined from 7.3% in 2024 to 7.1% in 2025, although real manufacturing value added grew by 2.0%. The figures measure different things, but together they raise an important question: how can Kenya translate the growing demand in sectors such as renewable energy into opportunities for local industry?

There is no need to view imported equipment as the enemy. International manufacturers offer proven products, specialized expertise, and economies of scale that would be difficult for many local firms to match immediately. The concern is whether we are doing enough to build our own capabilities alongside these imports. When replacement parts are delayed, shipping costs rise, or exchange rates shift, projects can become more expensive, and repairs can take longer. Local suppliers, repair workshops, and testing facilities would help reduce dependence on distant supply chains.

Local engineering can also make a practical difference in how equipment performs. Solar installations in dusty or hot environments require suitable protection and regular maintenance. Remote sites may be difficult to reach when a system develops a fault. Kenyan firms could respond by producing durable mounting structures and enclosures, developing remote-monitoring tools, and offering faster diagnostic and repair services. These are useful places to begin building a competitive industry.

Several institutions have a role to play, although their responsibilities should remain separate.

i. **The Ministry of Investments, Trade, and Industry (MITI)** can help manufacturers overcome barriers to investment through appropriate incentives, clearer administrative processes, and carefully planned measures that encourage local sourcing.

ii. **The Energy and Petroleum Regulatory Authority (EPRA)** should continue to uphold technical and safety requirements, ensuring that locally manufactured equipment performs reliably and meets applicable standards.

iii. **Kenya Industrial Research and Development Institute (KIRDI)** can help businesses test prototypes, improve designs, and determine whether products are ready for commercial production.

iv. **Technical Universities**: Can provide students with more opportunities to work on real manufacturing and engineering challenges through partnerships with local firms, particularly in power electronics, battery systems, and automation.

v. **Private Manufacturers:** Can identify products that they can realistically produce, such as mounting frames, protective enclosures, and selected electrical components. Assembly, maintenance, and monitoring services can also provide entry points before firms invest in more complex manufacturing processes.

For these ideas to work, manufacturers need affordable financing, access to reliable testing facilities, skilled workers, and a reasonably predictable market for their products. Partnerships with international companies can help local businesses acquire technical skills. Any local content requirements should be introduced gradually, with quality, safety, and overall project costs in view.

Kenya does not need to produce every solar panel, battery cell, or electronic component within its borders. An important task is to identify where local businesses can add genuine value and provide them with a fair opportunity to grow. For Kenyan engineers, this is about applying our knowledge to problems we understand, working with manufacturers to turn ideas into useful products, and helping to build businesses that can employ and train the next generation.

Our renewable energy achievements should be measured not only by the electricity we generate but also by what we learn to design, what we make locally, and the skilled jobs we create.

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Student Voices



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Engineering Kenya's Renewable Energy Future: How Students Can Turn Theory into Sustainable Solutions

Kenya's renewable energy future will be shaped not only by the resources available, but also by engineers who can transform those resources into reliable, affordable and sustainable systems. From geothermal plants and solar farms to wind and hydropower, Kenya has significant renewable energy potential, yet challenges remain in energy conversion, grid integration, storage, materials, efficiency and intelligent control.

For engineering students, subjects such as thermodynamics, fluid mechanics, electrical engineering, materials engineering, control engineering and design are practical tools for addressing these challenges. Thermodynamics helps optimise energy conversion and geothermal systems; fluid mechanics supports efficient design of hydro, wind and geothermal systems; electrical engineering enables grid integration, power conversion and microgrids; while materials engineering improves durability, battery performance and recyclability. Control and automation can make renewable systems smarter through sensors, PLCs, SCADA and technologies such as Maximum Power Point Tracking.

Energy storage is equally important because renewable generation varies with weather and time. Batteries, pumped hydro, thermal storage and emerging technologies can help balance supply and demand.

Most importantly, students can contribute through practical, multidisciplinary projects in areas such as smart energy monitoring, solar powered agriculture, microgrids and energy storage. Solutions must also be designed for Kenyan realities, considering cost, climate, infrastructure, local skills and maintenance.

The opportunity is clear: engineering students can turn classroom equations into technologies that strengthen Kenya's energy future.

Turning Wasted Water Pressure into Power

Across Kenya's highlands, gravity-fed water schemes carry water from mountain intakes to villages. Pressure Reducing Valves (PRVs) throttle the excess pressure so pipes don't burst. That pressure is energy, and it is lost as heat and noise. Kenya's water regulator does not require utilities to report it.

A Pump-as-Turbine (PAT) is an ordinary centrifugal pump run in reverse to generate electricity. It costs roughly USD 200 to 2,000, against USD 5,000 to 50,000 for a purpose-built micro-turbine, and local mechanics can maintain it.

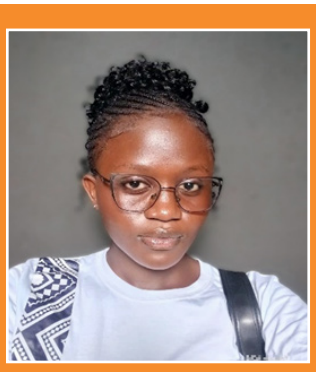
I have developed a nine-step site assessment method and a GIS screening tool using free SRTM elevation data and water scheme registers. Checked against a published Ethiopian site, my net head of 14.0 m came within 4.6% of the reference result.

A pilot on 30 synthetic schemes on the Aberdare slopes suggested about 181 kW is recoverable. Across Kenya's roughly 2,800 gravity schemes, the theoretical potential is 1 to 6.8 MW.

The hydraulics is not the hard part. Demand is. Linking the power to productive uses such as milling can cut payback to about five years.



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Building a Career in Renewable Energy

Renewable energy is emerging as one of the most dynamic career fields for engineers, offering opportunities across electrical, mechanical, civil and chemical engineering. As Kenya accelerates its transition to cleaner and more resilient energy systems, engineers are needed to design, develop, operate and maintain renewable energy technologies and infrastructure.

Electrical engineers contribute to solar photovoltaic systems, wind power, grid integration and battery storage, while mechanical engineers work in geothermal plants, wind turbines, equipment manufacturing, operations and maintenance. Civil engineers support foundations, site development and energy infrastructure, while chemical engineers contribute to battery technologies, green hydrogen and biomass processing.

Kenya offers opportunities across solar, wind, geothermal, battery storage and mini-grid projects. Additional career pathways exist in engineering, procurement and construction (EPC) companies, consulting, manufacturing, government and research institutions.

Aspiring engineers can prepare for these opportunities by strengthening their technical skills, gaining practical experience through internships and industrial attachments, learning relevant engineering software and developing professional industry networks. Combining a strong engineering foundation with renewable energy expertise can significantly enhance career prospects.

With Kenya's renewable energy sector continuing to expand, young engineers have an opportunity to contribute to projects that improve energy access, strengthen sustainability and support the country's economic and industrial development.

Two Batteries, One Brain

After sunset, Kenya's solar-powered clinics, schools and mini-grids depend entirely on their storage.

A lithium iron phosphate ($LiFePO_4$) battery system is a common choice: safe, long-lived and tolerant of daily cycling. But no single chemistry does everything. Vanadium redox flow batteries store energy in liquid electrolyte (V^{2+}/V^{3+} and VO^{2+}/VO_2^{+}), so capacity grows by enlarging the tanks, not the stack, and the electrolyte barely degrades with cycling. The catch: lower efficiency, pump losses, and costly electrolyte that can be hard to source locally.

Why accept those weaknesses? Because each battery covers the other's gap: $LiFePO_4$ absorbs fast power swings while the flow battery supplies slow, multi-hour energy. An Energy Management System (EMS) decides which battery serves which load; a Battery Management System (BMS) protects each from damage. Together they reduce the uncertainty of solar.

That EMS is a student project waiting to happen. Simulate its control logic in MATLAB/Simulink or Python, then prototype with an ESP32, sensors and a live dashboard. You will practice electrochemistry, power electronics, embedded programming and data analysis: skills that build a standout final-year project, a result worth presenting and a foothold in Kenya's solar sector. Start small; the clean energy transition needs builders, and we are the ones to do it.



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The Renewable Energy Engineer of Tomorrow: Skills Students Need for Kenya's Energy Transition

Kenya's proposed $1 billion Microsoft-G42 data-center project in Olkaria, announced in 2024, was intended to run on geothermal energy and support the country's digital economy. However, President William Ruto later highlighted the scale of its electricity requirements, stating that powering the data center could require switching off half the country. This raises a critical question; can Kenya's energy systems sustainably support the growing demands of digitalisation and industrialization?

As energy-intensive technologies expand, Kenya needs engineers equipped to develop reliable, efficient and resilient renewable energy systems. The engineer of tomorrow must possess practical skills that go beyond theoretical knowledge.

Students should develop hands-on competencies in solar PV, wind and geothermal energy, alongside energy storage technologies that support reliable power supply. Understanding energy efficiency, system optimization and the integration of renewable energy into existing power networks is equally important.

Proficiency in simulation tools, instrumentation and data analysis will enable engineers to design, monitor and improve energy systems. Project management, financial planning, teamwork and communication are also essential for transforming technical ideas into viable energy projects.

The data-center challenge demonstrates that renewable energy engineering is not simply about generating more electricity. It is about developing systems capable of meeting growing demand without compromising sustainability, reliability or affordability.

Engineering students must therefore be encouraged to pursue practical training, innovation, industry collaboration and problem-solving. Universities and professional institutions such as the Institution of Engineers of Kenya (IEK) have an important role in preparing graduates for these demands.

The renewable energy engineer of tomorrow must be a technically capable, innovative and adaptable professional, ready to help Kenya power its digital and industrial future sustainably.

The Renewable Energy Engineer of Tomorrow: Skills Students Need for Kenya's Energy

Kenya's transition towards cleaner and more sustainable energy is creating new opportunities for engineers. As renewable technologies continues to develop, engineering students must prepare themselves with skills that go beyond classroom theory.

Future engineers need practical knowledge in solar photovoltaic (PV), wind and geothermal energy systems. They should understand how to design, operate, monitor and maintain these technologies. Energy storage, particularly battery systems, is also becoming important for improving the reliability of renewable energy.

Digital competence will further shape the future of engineering. Skills in simulation, instrumentation and data analysis can help engineers monitor systems, predict performance and make informed decisions. Understanding energy efficiency can enable engineers to develop solutions that reduce energy consumption and costs.

Technical knowledge alone, however, is not enough. Engineers also need project management, communication, teamwork, problem-solving and leadership skills.

Students should therefore seek practical projects, internships, industry exposure and professional mentorship

As Kenya moves towards a sustainable energy future, are we, as the engineers of tomorrow, prepared with the skills and mindset needed to power that future?



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