8. Off-grid solar PV and geothermal in Kenya

Vincent Ogaya (Kenya Climate Innovation Center)

This case study on Kenya focuses on the Kenya Off-grid Solar Access Project (KOSAP) and its impacts on innovation. KOSAP is an initiative by the World Bank and Kenya's Ministry of Energy aimed at enhancing energy access in underserved Kenyan counties with the goal of promoting solar technology use, largely through a distributed model. Notably, while KOSAP lacked a specific innovation objective, it has nonetheless succeeded in harnessing Kenya's fintech innovation community to create an internationally competitive cohort of private companies engaged in the financing and sale of solar PV home systems.

The case study also addresses the impact of geothermal energy development on Kenya's energy technology landscape. In particular, the creation of local expertise in geothermal project development and execution by state-owned enterprises has led to Kenya gaining technological capabilities that now offer potential export opportunities.

Country context

Kenya is the largest economy in East Africa by GDP and the seventh largest in Africa. Its population is also the seventh largest in Africa, at around 54 million. It is classified as a lower middle-income country. Kenya's economy has expanded robustly in the past two decades, at an annual average of 4.2%, much higher than the 1.7% average it recorded in the 1990s and higher than the sub-Saharan average. Since 2014 the country's growth rate has been slightly higher, at around 5%, and has been driven by the expansion of the service sector, in particular financial services, tourism and transport. This growth has helped reduce the poverty rate from 37% in 2005 to 27% in 2019.

Kenya launched its Vision 2030 programme in 2008 as a guiding document for the transformation of the nation into a globally competitive, industrialised, middle-income country with high quality life for everyone. Infrastructure development, including for energy, is emphasised strongly in Vision 2030. The programme involved extensive stakeholder dialogue among government bodies, private enterprises and civil society. It is broadly considered to capture a consensus ambition for the country's future.

However, progress in diversifying the economy and boosting growth has been hit in recent years by several crises, including the global pandemic, inflationary pressures, commodity price volatility, high debt costs, the worst drought in four decades, violent flooding and tightening global financing conditions, which put major pressure on the exchange rate and foreign exchange reserves. The drought in 2021 was declared a national emergency by the government and left an estimated 2.8 million people in need of urgent food assistance, with some requiring malnutrition treatment and smallholder farmers needing emergency finance. The 2019-2020 locust invasion was described as the worst in 70 years, leading to cereal supply disruption and shortages and a rise in food prices that pushed large amounts of the population into poverty. Kenya is particularly vulnerable to the pass-through effect of rising global energy prices on domestic food prices, as most of its staple foods are imported. Floods in early 2024 displaced over 300 000 people and damaged infrastructure.

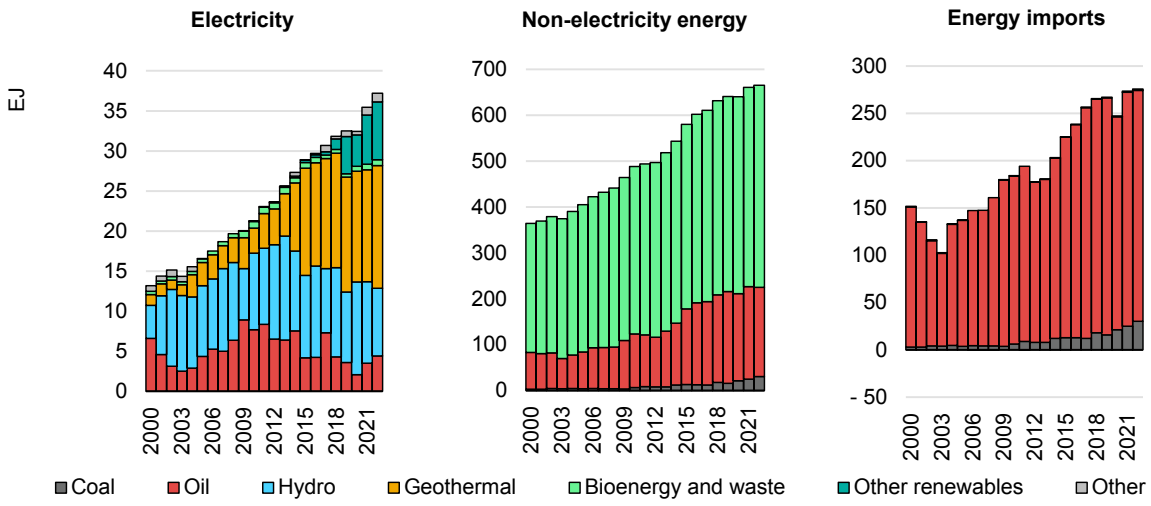
In the global context, Kenya's human development index score is relatively low, ranking 146 out of 189 countries. A significant portion of Kenya's economy is informal, and is estimated to be equivalent to as much as 25-30% of the country's official GDP. However, Kenya's internet connectivity rate is relatively high for the region, at 30% of the population in 2020.

Kenya is a presidential representative democratic republic, whereby the president is both head of state and head of government. Its governance structure has a high level of devolution to 47 county governments. A governor oversees the affairs of each county government, and this executive branch – along with the president – has a major role in setting government policy. However, legislation must be passed by the parliament or, at county level, by a county assembly.

Energy sector context

Kenya's energy consumption has grown by 86% since 2000, most of which has been supplied by bioenergy and oil. Bioenergy is largely reliant on traditional gathering of wood fuel, which is a time-consuming practice with serious health and equality impacts on the population. Electricity, while accounting for just 5% of total energy demand, has grown more steeply than other forms of energy and has undergone a remarkable shift from reliance on hydropower and oil to a situation where most electricity is now from geothermal and a rising share is from solar PV and wind. KenGen, the state-owned electricity generation company, indicates that demand for electricity has been steadily rising over recent years. Peak demand is projected to grow at an average of 3.1% annually in coming years. At the same time, the government has set a target of 100% renewable electricity by 2030, a goal that appears feasible based on current trends.

Figure 8.1 Energy sources for electricity and other uses, and level of imports, Kenya, 2000-2022



Notes: Electricity and non-electricity energy are shown on a final consumption basis. Imports are shown net of exports. "Other" refers to imported or exported electricity.

Source: IEA (2024), World Energy Balances.

The expansion of renewable electricity has helped Kenya deliver electricity access to almost three-quarters of its population and to 97.5% of those in urban areas. While this fell short of the goal of the 2015 Last Mile Connectivity Programme to achieve universal access by 2020, it represents an enormous improvement from a level of 14% in 2010. The programme helped the Kenya Power and Lighting Company (KPLC) – a public company with 51% government ownership – to install new transformers and extend the low-voltage network with a USD 900 million budget supported by the African Development Bank and European bilateral and multilateral development finance institutions, in addition to Kenyan government funds. Kenya now has one of the highest electricity access rates in sub-Saharan Africa, although, like many other African countries, the level of access has declined somewhat since 2020 as consumers have faced lower purchasing power due to incomes being hit by the global pandemic, drought and subsequent commodity price spikes. In addition, electricity suppliers are grappling with climbing debt burdens as they shoulder losses to keep bills affordable.

Kenya's centralised grid infrastructure and electricity supplies are not always reliable, partly due to the stretched finances of KPLC. Blackouts are common and this has a negative impact on the country's economic productivity as well as social outcomes. A rate of roughly one power outage per week was recorded in 2013 with a nearly six-hour average outage duration, and 83% of firms experience power shortages. In October 2021 Kenya announced a plan to create a super energy services company as a unit within KPLC. This company is intended to develop energy efficiency projects for the public and the private sectors.

Among the major investments in the power grid that are under consideration, the 8 000 km North–South Power Transmission Corridor linking Egypt with South Africa is perhaps the most ambitious. It could link Kenya to hydropower resources in Ethiopia and elsewhere while bolstering supply resilience through diversity. It would complement parallel efforts to build an international power market – the Eastern Africa Power Pool – which has been under development since 2005 to facilitate cross-border power trade among 11 participating nations. However, little has been accomplished since creation of the pool, as there are technical and political barriers to its operationalisation.

Geothermal sources have provided most of the additional supply of grid-connected electricity. Kenya has the world's seventh-largest geothermal potential and has made concerted efforts to exploit this natural resource. Geothermal electricity was first introduced to Kenya in 1981, but did not become a major component of the electricity mix until the opening in 2014 of the Olkaria IV power plant, which was co-financed by the World Bank and European Investment Bank. With nearly 900 MW now installed, Kenya's geothermal power output is the eighth largest in the world and further expansion is underway following a positive government evaluation of the costs and high load factors.

Alongside geothermal, there has been investment in solar PV and wind energy. Kenya hosts Africa's largest wind farm, which became operational with a capacity of 310 MW in 2019, after construction began in 2014. The country's installed utility-scale solar PV capacity also includes a 50 MW plant that is the largest in East and Central Africa. Off-grid deployment of solar PV has also had a significant impact, especially in rural Kenya. The country has been a pioneer in the development of pay-as-you-go (PAYG) business models for solar home systems and mini-grids, integrating digital communications and banking technologies ("mobile money") along with appliances designed to run directly from solar and battery systems. Ethiopia and Kenya together accounted for 30% of sales of global solar home systems and solar appliances in 2021. In addition, Kenya has around 40 MW of small hydropower plants.

In 2021 Kenya's net oil imports were equivalent to around 40 million barrels of oil, nearly twice as much as 20 years before. The cost of these imports was around USD 3 billion, a value that increased to around USD 5 billion in just one year when oil prices rose in 2022. Alongside energy efficiency and electrification of transport, recent offshore oil discoveries could provide a way of reducing the import bill. The region is attracting multinational companies, including Chinese oil companies, looking to invest in the Lokichar South Basin, discovered in 2012. After initial optimism, Lamu Basin was deemed unviable in 2022 due to a lack of accessible oil. Plans for an export pipeline are still in the design phase and poor infrastructure has previously hampered oil developments; the long-planned Uganda–Kenya Petroleum Products Pipeline is delayed until around 2030.

However, tackling climate change has become a higher priority topic in Kenya, which is among the top 40 most vulnerable countries to climate change. Among other impacts, the loss of Mount Kenya's glacier – which could happen as soon as 2030 – would lead to river shrinkage, affecting up to 85 000 people annually, reducing hydropower generation capacity and costing Kenya some USD 50 million every year. As part of its commitments under the Paris Agreement, Kenya has pledged to reduce greenhouse gas emissions by 32% by 2030 compared to a forward-looking business-as-usual scenario.

Innovation context

In recent years Kenya has nurtured a burgeoning start-up scene, with innovators securing funds to build companies in financial, agriculture, health, commerce and education technology areas. In most cases their products involve digital software and systems. Over the past 20 years Kenya has emerged as a pioneer in "mobile money" – banking services, including micro loans, via mobile phones. A bottom-up burst of innovation in this area has led to dramatic changes in the country's payments and banking, including giving parts of the population access to the financial system for the first time. In 2022 Kenya was ranked 88th in the world for innovation performance, and third in sub-Saharan Africa. Nairobi now sits alongside Cairo, Cape Town, Lagos and Johannesburg as one of Africa's top start-up ecosystems.

This outcome was not entirely government directed. Kenya has a relatively high rate of education and literacy compared to its neighbours, but one in five adults are still illiterate. Government funding and support for R&D has been sporadic and inconsistent over the years. Much innovation occurs in the informal economy, where there are pressures to find cheaper ways to provide services and rapid exchange of knowledge in the absence of intellectual property protections. It was only in 2013 that the Kenya National Innovation Agency (KENIA) was founded by the Science, Technology and Innovation Act. It has a mandate to stimulate socio-economic progress through innovation in line with Vision 2030. At around the same time, the Kenya Climate Innovation Center was established (Box 8.1).

The government has also recognised the potential for its youth to contribute to technology development with appropriate training. In 2017, 55% of 18-35-year-olds were unemployed, with unemployment twice as likely in the 18-25-year age bracket than in the 26-35-year age bracket. There has been recent investment in technical and vocational education and training institutes to complement existing colleges and universities.

Box 8.1 The Kenya Climate Innovation Center

The Kenya Climate Innovation Center (KCIC) was established in 2012 as part of the World Bank's infoDev initiative. It was the first in a global network of Climate Innovation Centers whose design and establishment arose from the need to help developing countries overcome the challenges they face in acquiring, developing and deploying climate technologies in their local contexts. KCIC aims to foster a localised and durable approach to climate change-related innovation and has a mandate to accelerate the development, deployment and commercialisation of relevant technologies.

KCIC aims to support innovators to overcome barriers that are especially pronounced in developing countries, including inadequate skills, limited financial support and inhibitive policy frameworks, as well limited access to markets for climate technologies. Its services include business advice, technical assistance, financial support and policy advocacy to help create markets and support further innovation. As well as helping to tackle climate concerns, job creation is an objective of KCIC and a pressing need in Kenya.

Initially supported primarily by the World Bank, Denmark and the United Kingdom, KCIC has broadened its funding base as it has grown. In addition to working in Kenya, it has expanded to offer services elsewhere in East Africa. To do so, it now includes support from multilateral development partners like the European Union and foundations such as the IKEA Foundation and the Mott Foundation. By the end of 2022 KCIC had incubated over 3 000 businesses in areas such as renewable energy, agribusiness, forestry, waste and water management. This is estimated to have generated nearly 40 000 jobs and enable half a million tonnes of CO_2 emissions to be avoided. In recognition of its impact, KCIC was designated as the implementing agency of the "Promote Climate Technologies and Innovation" initiatives for 2018-2022 under Kenya's Vision 2030 agenda.

The case of off-grid solar PV in Kenya

Less than one-third of Kenyans live in urban areas and the rural population has long suffered from a much lower level of access to electricity. Efforts to connect rural communities to the power grid began in 1973 as an approach to stemming rural–urban migration by improving social amenities and employment opportunities. However, by 2004 just 91 000 people (0.3% of the target population) had benefited from new connections and the rural electrification programme was suffering operating losses. The 2004 Sessional Paper No. 4 on Energy set a goal of increasing rural electrification from 4% to 40% by 2020, and finding new funds

to achieve it. The paper also marked the formal recognition of two important changes in the Kenyan energy landscape at that time:

- It noted that the previous three years had seen the annual installation of small solar PV home systems grow by 20 000 units per year, reaching 200 000 installed in total, and it made a direct link to the rural electrification challenge, saying that "the potential for photovoltaic solar home systems is virtually untapped. It is therefore expected that with the diversification of rural electrification strategies, the number of installed photovoltaic solar home systems will grow substantially".
- It expressed concern that past efforts in energy R&D had focused on policy analysis and demonstration activities, but limited attention had been given to technology-oriented research. It advocated a "a national energy research strategy, including defining specific roles of government, energy suppliers and private sector in R&D funding, increasing budgetary allocation for R&D, improving co-ordination and reporting mechanisms on energy research activities and results, and facilitation of local participation in international and regional research activities". As an example, the paper said that developers and consumers of wind energy needed to develop the technical capacity to procure and adapt wind technology for use in different conditions.

In 2007, when Vision 2030 forged consensus on the future among government institutions, the high-level strategic document highlighted renewable energy as a priority alongside electricity market reform, cross-border electricity interconnection and the exploitation of coal. It also said that the public resources for scientific research and workforce training would be increased.

However, between 2004 and 2015 there was scant progress towards realising the opportunities for off-grid solar PV and technology innovation identified in Sessional Paper No. 4. Strategic misalignments can be seen in socio-political support as outlined in two strategic documents in 2015. The Green Economy Strategy and Implementation Plan outlined actions to reach a 75% share of renewable energy in Kenya by 2025 and included reform of the feed-in-tariff subsidy policy to incentivise off-grid projects, which had been excluded up to that point. It also promoted the creation of "green-tech" start-ups through innovation and replication, and outlined the need for actions in the areas of knowledge management, monitoring and evaluation. In the same year, the Last Mile Connectivity Programme was launched to focus exclusively on extending the national grid to rural communities without any mandate for promoting renewable energy. This programme was managed by KPLC and the Rural Electrification Agency (REA) that had been established in 2006 to help rural communities connect to the grid.

The Kenya Off-Grid Solar Access Project accelerates solar PV uptake through international co-operation

A defining change in the outlook for solar PV in Kenya was the partnership between the Ministry of Energy and Petroleum and the World Bank in 2016 that led to the launch of the five-year Kenya Off-grid Solar Access Project (KOSAP) in 2018. The funding that the World Bank could bring, combined with the World Bank's mandate to support livelihoods and renewable energy, enabled a large-scale project that was on the margins of national energy policy, which was focused on market reform and grid expansion. KOSAP's goal is to use its USD 150 million budget to provide energy access to 14 underserved counties (representing 20% of the population and 72% of Kenya's land area) via solar technology, especially in areas further from the national grid.[1] These counties have population densities one-quarter of the national average, and poor road, water and social infrastructure.

The component objectives of KOSAP relate to different types of technologies, depending on the identified needs and least costly options for meeting them:

- Construction of 120 mini-grids in 12 counties for community facilities, enterprises and households, combining solar PV, battery storage and diesel gensets. The model for this component is public–private partnership whereby the project funding is used for the mini-grid network and private and public funds co-finance the generation facilities. Construction of the mini-grids is shared between KPLC and the Rural Electrification and Renewable Energy Corporation (REREC).[2] Accountable private service providers bid to manage the mini-grid construction and sign offtake and maintenance contracts of up to 10 years with KPLC, which collects the customer payments at the same tariff as for the national grid.
- The sale of 250 000 stand-alone solar home systems and 150 000 clean cooking solutions. For most households, these are the least-cost options. Project funds are used to provide grants and loans to private enterprises to help them expand their operations into the target communities.
- Installation in 387 community facilities of stand-alone solar PV systems and retrofitting of 380 existing community boreholes to be pumped by solar PV instead of diesel. The target facilities include health centres, secondary schools and administrative offices. Private sector contractors are selected competitively for each area and overseen by KPLC (in the case of new PV pumping systems) or REREC (in the case of borehole retrofits).

While the KOSAP implementation plan recognises the role that technology innovation had played in enabling the project's concept – international innovation in solar PV and Kenyan innovation in mobile payments – it contains no explicit

[1] While it is not discussed in this chapter, KOSAP also includes measures to support uptake of clean cooking technologies.
[2] The successor organisation to the REA. REREC is responsible for the rural electrification programme fund and master plan, including sourcing additional funds. It implements elements of the World Bank Kenya Electricity Modernization Project, which includes construction of mini-grids and sales of electricity to KPLC. It promotes renewable energy in Kenya.

references to objectives for technology innovation outcomes. It has, however, included training for solar technicians and entrepreneurs, as well as several aspects that make KOSAP a transformative project in Kenya.

One notable aspect is the involvement of all Kenya's key energy-related institutions. As manager of the World Bank partnership with accountability for the use of the funds, the Ministry of Energy and Petroleum co-ordinates to ensure alignment among different institutions and helps to ensure efficiency. The Energy and Petroleum Regulatory Authority is a regulatory authority for the energy sector in Kenya and has responsibility in KOSAP for technology standards and fair pricing of electricity from off-grid technologies via tariffs. The key bodies for grid modernisation and electrification – KPLC and REREC – are also involved as implementers to avoid development of a two-tier system by ensuring that the remote counties receive the same tariffs and service as elsewhere in Kenya.

Another key element of the project is the way that digital technologies are integrated into its core (Table 8.1). This makes direct use of Kenya's leadership in mobile communications technology for microfinance and PAYG payments, which was developed over the preceding decade and had already been applied with some success to off-grid solar in urban areas. Arguably, KOSAP was made possible by the existing local expertise in this area from the Kenyan "fintech" sector, which enabled the programme's funds to be directed via private PAYG providers that offered cutting-edge and affordable financing to the rural poor. This competitive environment created incentives for the companies to update their products and maintain lasting relationships with customers.

Table 8.1. Ways in which digital technologies are integrated into KOSAP

Digital service	Use in KOSAP
Communication	KOSAP's operators use text and interactive voice messaging to communicate with beneficiaries to gather feedback and disseminate important information.
e-learning	Used to educate communities about maintenance and the benefits of renewable energy, thereby fostering a sense of ownership and responsibility.
Geospatial data and mapping	Identifying areas in need of KOSAP services for efficient allocation of resources and to assist the customisation of interventions according to local needs.
Mobile money	Convenient and secure remote monthly payment systems, plus availability of micro loans that foster financial inclusion and are backed by World Bank guarantees. This has helped suppliers bundle other services, including hot water and clean cookstoves, with the solar electricity offering.
New apps	User-friendly applications were created for KOSAP to enhance user interaction with the systems and offer insights into energy consumption patterns.

Digital service	Use in KOSAP
Performance monitoring	The installed systems generate real-time data that are analysed by the project co-ordinators to adapt the means of implementation.
Smart metering	High-granularity energy consumption data facilitate reliable and transparent billing and hence trust between suppliers and customers. They can also be used to provide advice on efficient use of energy.

KOSAP has also had a strong component related to education from the outset. It was considered important to provide clear and thorough information about the technologies and services, their benefits and how to access them. One-to-one communication channels for regular feedback were put in place, including education campaigns, demonstrations and guidance on operation and maintenance. The acceptance of local opinion leaders was a primary target, given their importance in village contexts.

It is important to recognise that the KOSAP project has not been implemented in a vacuum, but interacts with other relevant policy measures. These include tax incentives for the purchase of renewable energy products and regulatory guidelines for off-grid systems that mirror the performance standards of the national grid. In the initial documents for KOSAP, the World Bank identified the need to ensure that regulatory standards are adaptable to facilitate the entry of improvements to technologies and services that might occur during the duration of the project.

KOSAP's successes bring solar PV from the periphery to the centre of energy policy

Implementation of KOSAP was delayed by the global pandemic in 2020-2021 and its end date was extended to 2025. By mid-2024 considerable progress had been made against the project target for stand-alone solar home systems (70% of the target sales achieved).[3] Progress with mini-grid installations, community facilities and solar water pumps has been slower. In the case of mini-grids, bids for all projects were processed by the end of 2023 and licences have been issued. Construction is anticipated to start in 2024, but is contingent on World Bank approval of submitted bidding documentation as well as land acquisition processes. Though the timeline will be tight, fulfilment of the targets by the new end date is still possible.

The positive experience of using stand-alone solar PV systems to provide electricity access in Kenya changed the expectations of the country's top energy planners. KOSAP was a key element in this because it explicitly paired the

[3] Progress update based on information received in July 2024 from the Ministry of Energy and Petroleum.

renewable energy and rural electrification policy goals with an approach to implementation that fostered lasting contractual relationships and inclusive access to capital. Influentially, initiatives to support uptake of solar home systems in Kenya led to their installation far exceeding new grid connections and on-grid solar capacity additions.

In 2018 and 2019 Kenya issued a National Energy Policy and then a new Energy Act, which was first major energy legislation since 2012 and consolidated various policy strands under one framework. As well as guiding the use of renewable energy via the national grid, the Act promotes small-scale and distributed renewable energy with a feed-in-tariff. Among the top objectives for this tariff are "encouraging local distributed generation thereby reducing demand on the network and technical losses associated with transmission and distribution of electricity over long distances [and] encouraging uptake of, and stimulate innovation in, renewable energy technology". It also established new electricity market design rules, including formalising the role of innovative, independent companies as electricity retailers subject to the same conditions as large, centralised utilities.

KOSAP influenced the development of policy and the enactment of the 2019 Energy Act in several ways. The emerging successes of the KOSAP project were referenced at public participation forums on the new policy and law, underlining the need to make energy affordable and accessible to all, a goal that was expressly stated in the Act. The role of the REA – now REREC – was expanded to incorporate renewable energy as well as rural electrification, forging a stronger link between them and a default expectation that rural areas, including schools and institutions, would be electrified via their abundant solar and wind resources. The Act also created a Rural Electrification Fund to support tariffs that respond to the needs of rural users without unnecessarily subsidising consumption, and it enabled market-based measures for the private sector scale-up of off-grid solar PV, both things that were pioneered in Kenya by KOSAP. Under the Act, responsibility for ensuring a conducive environment for private sector investment was elevated to the Cabinet Secretary.

Despite a lack of direct technology innovation policies, "market pull" drivers have yielded some innovation outcomes

Off-grid solar PV in Kenya scaled up significantly after 2015 and in particular with the KOSAP project, producing unanticipated innovation outcomes. This technology was not a good fit with the country's then main strategy to modernise its electricity grid, connect it to neighbouring countries and extend it to rural areas. While the centralised grid strategy had a strong and successful focus on

renewables, the main priorities were large hydro, geothermal and, later, wind energy plants. Thus, the new market for solar PV, when it arose via funding from international finance, created opportunities for new technology approaches and the creation of entirely new businesses. The integration of micro finance and mobile payment solutions is a good example of new players in the private sector responding to the changes in the market.

Under KOSAP, Kenyan providers of equipment and services have been favoured by the small-scale nature of the installations, the value of local knowledge and the need to be registered within the Kenyan financial system. The project prioritised local content to support local businesses and help tailor the technologies and services to local needs. By providing funding – as grants and loans – and results-based finance, KOSAP addresses the lack of capital in the sector while also enabling start-ups and innovators to pilot, scale up and commercialise new technologies and business models, including for maintenance of installations. Participating firms have also been provided with access to collaboration with KPLC and universities to pilot new ideas in a less risky environment and learn from more established actors.

Some companies, such as M-KOPA, have now expanded their operations beyond Kenya. One of the smaller start-ups, Sunken Limited, was founded in 2018 and received funding from KCIC to manufacture solar home systems, water pumps, irrigation systems and clean cookstoves from local components. With a PAYG business model, it has now expanded from remote northwest Kenya to other parts of Kenya as well as regions of Uganda and South Sudan. Rafode Renewable Limited is a subsidiary of a Kenyan microfinance company and specialises in digital platforms for credit and payments that make its solar and clean cooking services affordable to low-income households. It has steadily expanded further into the remote North Rift area of Kenya.

This process of capacity building, innovation and manufacturing was dependent in large part on the national decision to impose no import duties on solar equipment. Access to the core and most technical components at lowest cost enabled Kenyan suppliers to integrate them into products and market them within KOSAP at affordable prices.

Another impact of the rise in rural electrification has been a change in the expectations for meeting national goals for access to clean cooking. To transition away from wood burning on open and inefficient stoves, LPG and efficient biomass cookstoves had long been the preferred options. The uptake of affordable solar PV has now enabled clean cooking goals to be set based on the electrification of cooking. This, in turn, is driving innovation in the replication of traditional cooking practices using technologies such as induction hobs. The Kenyan electric cooking campaign, Pika Na Power, uses television adverts, social media campaigns and

live cooking classes to promote electric cooking. There are strategies in place to boost electric cooking in urban and rural areas by overcoming cultural barriers through cooking classes, recipes for local cuisine using electric cookware, time-saving techniques and dish-preparation contests.

An important lesson that emerges from the KOSAP experience relates to the challenges of enforcement of standards in a decentralised project with multiple suppliers and installations. In some cases, products did not perform as expected or were not in line with regulations. The core components of these products were mostly imported. This has led to a review of the processes by which the Energy and Petroleum Regulatory Authority regulates energy products as it incorporates new types of technology and fast-moving iterations in product design. This element requires a careful balance between strong standards and allowing new ideas to access the market quickly as they may have the potential to lower renewable energy prices and accelerate inclusive energy transitions.

The case of geothermal energy technology in Kenya

Since 2010 geothermal energy supplies have grown fivefold in Kenya and now account for over 40% of electricity generation. After initial failed test wells in the 1950s and then the first successful pilot in the early 1980s, Kenya was the first and only African country to invest in geothermal energy production until Ethiopia followed in 1998. Kenya continues to invest in the technology, allocating over USD 150 million of its 2022/2023 national budget for geothermal power development. Its geothermal resource in the Great Rift Valley is vast and relatively easy to tap due to the high temperature and pressure.

Geothermal development has been managed in Kenya by KenGen. It has done this with a high level of international co-operation. The equipment has been supplied by international engineering firms including Mitsubishi, Hyundai, Toyota Tsusho and KEC International. Finance for the sequential projects has been provided by the Japan International Cooperation Agency, European Investment Bank, International Development Association, French Development Agency and the World Bank.

Over the years, these collaborations have built significant technical capabilities in KenGen and in Kenya more generally. Project development skills are one example: it took a full year to build the pilot plant at Olkaria, but the next 14 wells were built in four years. When the 2006 Energy Act liberalised parts of Kenya's electricity system, a new state-owned company – the Geothermal Development Company (GDC) – was formed to develop geothermal fields and sell steam to

KenGen and private investors. GDC has a centre of excellence for Kenya's geothermal operations and trains operators to mitigate the risk of a skills gap opening in the sector.

The biggest cost and risk in the geothermal development process is the upfront drilling. This step accumulates costs if the drilling campaign takes a long time and also carries the risk of not finding a suitable resource – a so-called "dry well". To speed up the drilling campaigns and the ability to bring new fields online, GDC has increased the number of drilling rigs it operates from one before 2010 to seven in 2018, while KenGen has a further three. However, this is far from the availability of drilling rigs in places with extensive oil and natural gas exploration, such as parts of the United States. To manage the risks associated with dry wells, the World Bank developed a Global Geothermal Development Plan in 2013 and mobilised several hundred million dollars, including for insuring the costs of unsuccessful drilling. Validating commercial viability of a geothermal resource is an unavoidable step often requiring USD 15-25 million in drilling costs or around 15% of the capital expenditure upfront, with no guarantee of return. Commercial debt is often not available to finance this step.

In 2015 GDC began exploring the direct use of Kenya's geothermal steam, which represents a new frontier in technology innovation. Through a collaboration with the United States Development Agency (USAID), it operates five direct-use pilot projects for uses including greenhouses, fish farming, milk pasteurisation, grain drying and laundry. These uses can directly replace fossil fuels in these industries, while enabling geothermal projects to sell steam that is not suitable for power generation. The next step is to explore whether new industrial parks can be established near geothermal resources, seeding new sources of local economic growth. Direct uses have the potential to benefit women in Kenya, as several of the target applications are typically women-led businesses. Kenya has set a quota for employment and training of women in the sector. Geothermal energy can also create new business opportunities.

This expertise has allowed Kenya to lead the co-ordination of countries in the region in an alliance for geothermal development. The potential for export of expertise – as well as power – is significant. Ethiopia has three projects under construction, and the country plans to increase its geothermal power capacity to 10 GW by 2030. Plans to develop geothermal energy are also under consideration in Eritrea and Djibouti, where KenGen is directly engaged in project development.

Another clean energy technology opportunity that has been enabled by geothermal expertise in Kenya relates to material extraction. Titanium is used in geothermal power plants to withstand the harsh operating environment. While titanium production has historically been concentrated in a limited number of countries – with Australia, Canada and South Africa together accounting for 40%

of global production – Kenya entered the sector in 2014. Since then, it has produced between 5% and 7.5% of global output; it is now in the top four African producers and among the top seven global producers, with 250-350 000 tonnes of output per year. Demand for titanium is expected to rise significantly, especially for clean energy technologies such as geothermal. In IEA climate-driven scenarios, mineral demand for geothermal technologies grows more than seven times over the coming two decades.

More recently, several start-ups have been launched in Kenya in the technology areas of direct capture of CO_2 from the air and geological CO_2 storage. These innovators are building directly on expertise gathered from the expansion of the geothermal sector since 2010.

Findings

Rural electrification via solar PV, especially through KOSAP, has had a major impact on Kenyan energy policy since 2015. The involvement of international finance enabled a large-scale project to be designed around a technology that was not among the top national energy policy priorities but was important to the World Bank, which was keen to support a deployment model for off-gird solar that could be replicated across sub-Saharan Africa. KOSAP's success moved solar PV from the periphery to the centre of Kenyan policy in the 2019 Energy Act and afterwards. This demonstrates that international co-operation can have a catalytic effect on a new technology that might otherwise struggle to receive central government support if it is in tension with the preferences and expertise of incumbents. By working in a "protected niche" for policy experimentation, which in this case was in remote communities far from planned grid expansions, greater alignment with the national vision was achieved through demonstration of effective rural electrification and innovation. Involving key stakeholders from Kenyan energy policy, such as KPLC and REREC, in project execution and tariff collection helped build trust and a shared vision of the co-existence of national grid, mini-grid and stand-alone systems.

Building on the strengths of the Kenyan technology innovation system has been central to the effectiveness of KOSAP. Notably, this included integration of mobile payments, micro finance and app development, but it also leveraged the healthy start-up ecosystem that had built up around the fintech sector in the past decade. Through KOSAP's "market pull" policies and smart design, new private companies have been able to scale up and become nationally and internationally competitive in the energy sector despite the lack of a well-funded national energy R&D programme or innovation objectives for KOSAP. Many of these start-ups have been engaged in the financing and sale of solar PV home systems (Table 8.2).

Table 8.2. Selected energy-related Kenyan start-ups founded since 2010

Start-up	Year founded	Technology area
M-KOPA Solar	2011	Off-grid solar PV retail solutions and solar home systems
PayGo Energy	2014	Clean cooking retail solutions
Solar Panda	2016	Off-grid solar PV retail solutions and solar home systems
Spark Possibilities	2016	Solar home systems
Keep It Cool	2019	Solar PV systems for commercial services
Agrotech+	2019	Solar PV systems for commercial services
ecobodaa	2020	Electric motorbikes
Ecosafi	2020	Clean cookstoves using waste biomass
Stima Mobility	2020	Electric motorbikes and battery swapping technology
BasiGo	2021	Electric buses and financing solutions
Cella Mineral Storage	2021	Geological CO_2 storage
Octavia Carbon	2022	Direct air capture of CO_2

The experience of KOSAP highlights the need to invest in institutions and capacities to monitor and regulate quality in a fast-moving small-scale technology area like solar home systems. The types of hardware supported by KOSAP were unfamiliar to the existing regulatory regime for energy in Kenya and were largely produced overseas. The need to adapt standards and strengthen enforcement emerged from the project as lessons learned. However, the incentivisation of private companies to compete and innovate is a core design feature of KOSAP. There must therefore be a balance between this and the regulatory requirements for safety and product quality that are essential but could stifle innovation or the adoption of the latest overseas technologies if too strict.

International finance and technology were also fundamental to the exploitation of Kenya's excellent geothermal resources. However, in a technology area like geothermal, considerable local expertise in project development and execution is necessary. This played well to the strengths of state-owned enterprises that are large enough to take on strategic government priorities in risky areas. As a first mover in Africa, Kenya has accumulated considerable capabilities in geothermal as well as suitable drilling rigs. After several decades of development, Kenya's technological capabilities have now opened opportunities to diversify and generate technology-based economic returns. These include the provision of technical services to neighbouring countries, the development of techniques and business models for direct use of geothermal steam, and the expansion into CO_2 capture and storage in Kenya.