11. Solar PV and rural electrification in Nigeria

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As Africa's largest economy and most populous nation, Nigeria plays a key role in the continent's transition to clean energy and has had a national net zero emissions target since 2021. However, despite abundant renewable resources, the country relies on fossil fuels and faces significant energy access and energy security challenges. Nigeria's efforts to diversify its energy mix with clean energy technologies since 2005 have largely focused on rural electrification via solar PV. It has made notable progress in this area with small-scale and off-grid projects. While technology innovation has been stated as a goal, it has been driven more by local and foreign private actors and less by government programmes. Public research funding remains weak. Under challenging currency exchange rate conditions, import tariffs on solar PV have so far mostly raised the cost of installations rather than spurring local development. The Rural Electrification Agency has emerged as a key institution for pioneering technology demonstrations and has partnered with international funders to accelerate the pace of uptake. It has also created opportunities for synergies with fast-growing innovation ecosystems in the financial and agricultural sectors. The rural electrification strategy and plan (RESIP) has been one of the main policies in this area; it was designed to expand electricity access in Nigeria and grow the renewable energy sector. As of 2023, the government is working to attract investment in solar manufacturing from foreign technology companies and has proposed R&D spending requirements for local firms, but whether this leads to domestic innovation will depend on strengthening the local innovation ecosystem.

Country context

Nigeria is Africa's second-largest economy and its most populous country. With a population of around 220 million people, it is the world's seventh most populous country. It is classified as a lower middle-income country. Nigeria's GDP has grown at an average of around 1% over the past five years, below its average of 5% since 2000, resulting in a level of GDP per capita that is above the average for sub-Saharan African countries and similar to that of Pakistan. However, in 2015 India and Nigeria had comparable levels of GDP per capita, with Pakistan's 15% lower, but India's is now 40% higher than Nigeria's. As of 2023, 42.5% of Nigerians live below the poverty line, although the government has set a goal of lifting

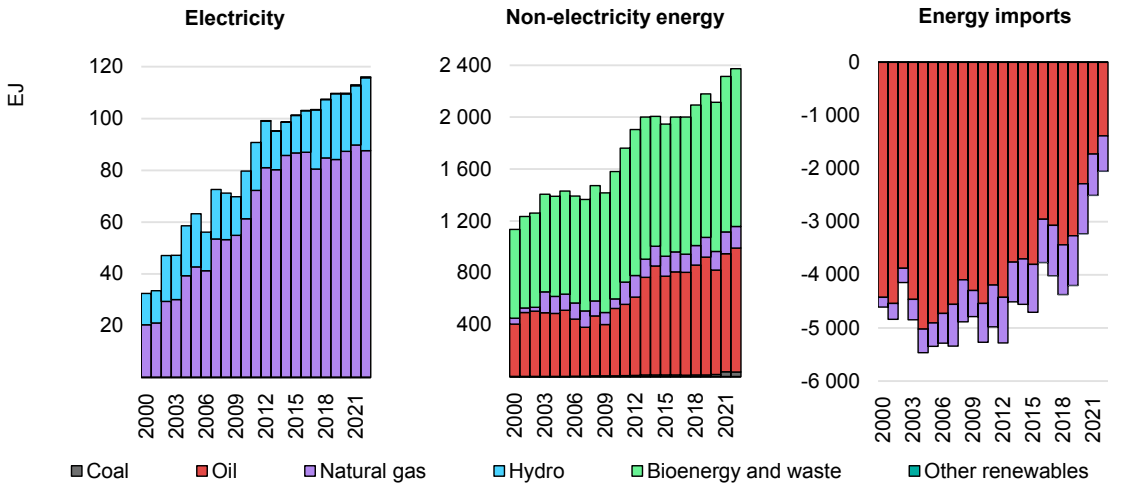
100 million Nigerians out of poverty by 2030, which would reduce the poverty rate almost to zero under expected population growth trends.

Economically, services are the largest sector in Nigeria at almost 60% of GDP in 2023, with agriculture adding a further 22% and the oil and gas sector adding 5%. The remaining balance is contributed by other industrial sectors. However, despite the relatively small contribution to overall GDP, the oil and gas sector dominates the energy landscape in Nigeria. It represents 65% of foreign exchange earnings and over recent decades has accounted for over 90% of export value, a level that is considerably higher than most other oil-exporting countries.

Energy sector context

Nigeria is an oil- and gas-producing country. In Africa its crude oil reserves are second only to Libya, and so too was its crude oil production in 2023. Its natural gas reserves are the largest in Africa. However, despite its sizeable crude oil and natural gas exports (Figure 11.1), Nigeria is a net importer of refined petroleum products due to low refinery capacity. This situation presents challenges for the economy, with imports of refined petroleum products reaching USD 7.75 billion in 2020, representing 14.5% of total imports. To reduce the price of imported fuel for citizens, the Nigerian government spent USD 4.5 billion on fuel subsidies in 2021, an amount equivalent to 35% of its oil and gas revenues and 2% of its GDP. Unplanned production interruptions and other disruptions have prevented Nigeria from exporting as much oil as intended in recent years. However, it is considered to be a leader in Africa for its efforts to reduce emissions and flaring of methane from its oil and gas sector and these could be economically valuable – it is estimated that Nigeria's high natural gas flaring rates lead to natural gas worth around USD 1 billion not being captured for sale each year.

Figure 11.1 Energy sources for electricity and other uses, and level of imports, Nigeria, 2000-2022

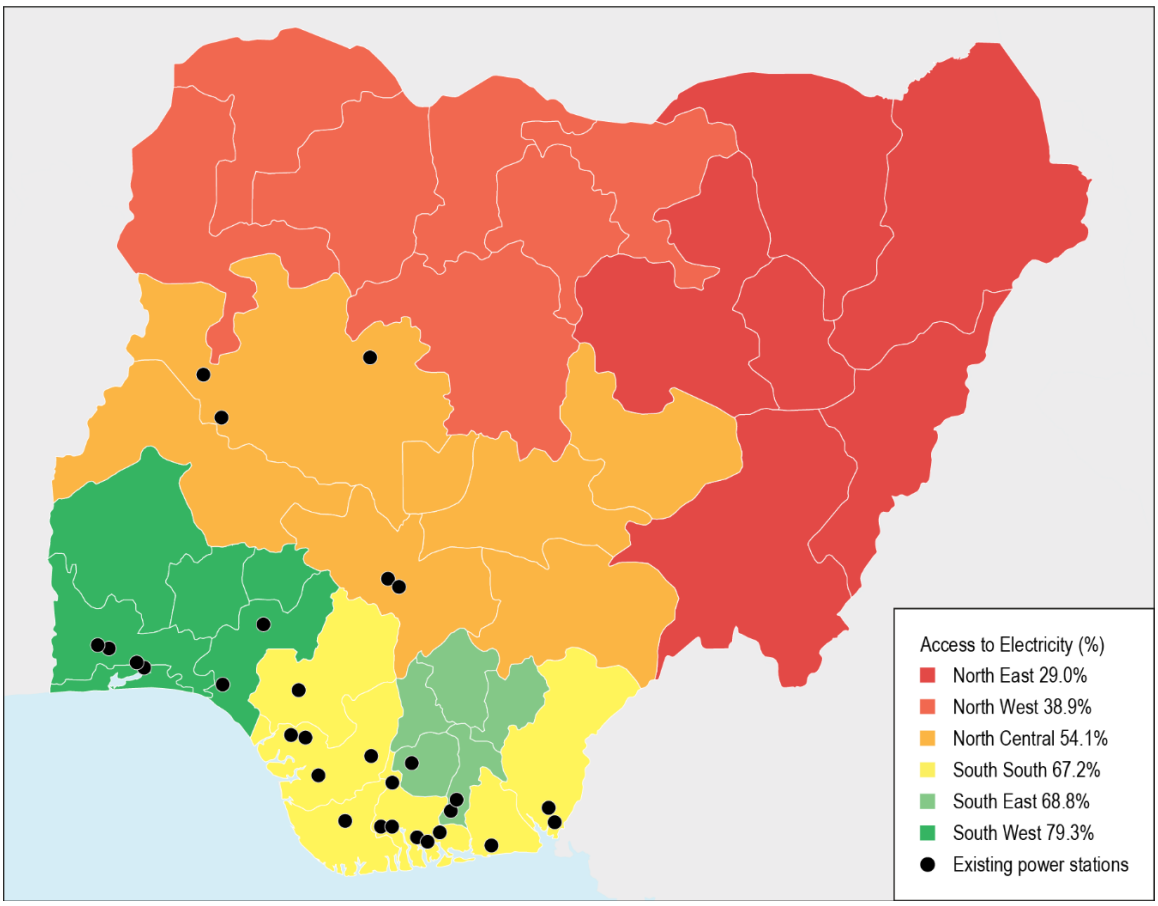


Notes: Electricity and non-electricity energy are shown on a final consumption basis. Imports are shown net of exports.
Source: IEA (2024), World Energy Balances.

Natural gas meets around 75% of electricity demand, with almost all of the rest supplied by hydropower. However, 40% of the population lack access to grid electricity and only 30% of the urban population has reliable access to Tier 5 electricity, which allows the operation of energy-intensive appliances such as air conditioners. Of those connected to grid electricity, 22% rely on additional non-grid sources such as generators, solar home systems and rechargeable batteries. There is a large gap between the total installed capacity of the 23 grid-connected plants on the electricity system (12 760 MW) and the available capacity of 7 788 MW.[1] The transmission network has a theoretical capacity of 8 500 MW, but has never conveyed more than 5 459 MW. Technical losses in the transmission network over the past five years on average have been between 8% and 13%. Many thermal power plants also struggle to procure sufficient fuel to meet demand. In 2014 survey data suggested that Nigerians may have been experiencing 4 000 hours of blackouts or more annually, equivalent to nearly 50% of the year. After China and India, there are more people living without access to clean cooking in Nigeria than in any other country. An estimated 83% of Nigerians lacked access to clean cooking in 2021, although this should decline as the government implements its clean cooking policy (Figure 11.2).

[1] The gap between installed and operational capacity can be traced to inefficiencies in the transmission and distribution infrastructure as well as loss of generation due to fuel availability.

Figure 11.2 Access to electricity and distribution of power stations across the regions and states of Nigeria



Source: Based on USAID (2022), Power Africa Annual Report 2022.

These inefficiencies have consequences for the economy. Most manufacturing facilities and other enterprises rely on backup diesel generators, which are costly and contribute to local air pollution. It has been estimated that challenges related to electricity provision cost the economy around 2% of GDP annually.

Electricity consumers in Nigeria pay much lower rates than the cost of electricity provision, and several reforms have been initiated to make power prices more cost-reflective. In 2019 the customer tariff was 30% of the average cost of supply. The Nigerian Bulk Electricity Trading Company (NBET), a state-owned enterprise, is the sole buyer of electricity from generation companies and the sole seller of electricity to all distribution companies. The fiscal gap between the cost of electricity supply and the amounts recovered via tariffs is covered by payments from NBET to distribution companies. It has been estimated that only 8% of total fiscal expenditure to reduce electricity prices for consumers benefits the poorest 40% of households, while less than 2% benefits the poorest 20%. Since 2020 the Nigerian Electricity Regulatory Commission has initiated reforms to make electricity tariffs cost-reflective and make the sector financially viable. The new

tariff model splits consumers into five bands, depending on the quality and duration of supply that they have access to. The lowest band is guaranteed at least four hours of supply. However, this system has faced opposition from labour unions and civil society groups concerned about the increases in the cost of living, given that electricity is still considered an expensive good for most low-income households.

The use of renewable energy has expanded in recent years but remains low. Hydropower output is growing steadily but its contribution to total electricity generation fell from 37% in 2000 to 24% in 2022. Solar PV has not yet grown above 0.3%, with the first grid-connected solar projects only approved in 2016. The Nigerian government has set a target of generating 30% of its electricity from renewable sources by 2030 and has launched several initiatives to promote renewable energy development. Much of the effort to spur solar PV deployment has not been for grid-connected projects, but has instead focused on off-grid and rural electrification where solar is in many cases the most appropriate and cheapest option for providing electricity access.

International companies have dominated Nigeria's oil and gas sector for decades. Shell, ExxonMobil and Chevron have all engaged in joint ventures with the state-owned Nigerian National Petroleum Corporation (NNPC). These companies have provided crucial technical expertise and capital, controlling a significant portion of the country's oil exploration since the 1950s. In contrast, international companies have not been present in Nigeria's electricity sector, in which control by a single state-owned monopoly was only recently changed by the privatisation of power generation and distribution companies.

Slight changes to the balance between international and domestic firms are underway in both the oil and electricity sectors. International oil companies are divesting from onshore and shallow water projects to concentrate on offshore production, partly due to environmental concerns. In the power sector, the government has engaged Siemens to help upgrade the power grid, and the introduction of solar PV has enabled international companies to invest and participate in the market. Some of these companies are international oil companies seeking to diversify, including Shell and TotalEnergies, which have both invested in companies to operate or sell solar PV systems in Nigeria.

Over the past two decades, Nigeria has implemented several clean energy and climate policies and laws to close its energy access and clean cooking gaps, bolster its energy security and transform itself into a green economy. The sequential issuing of key policy documents has helped communicate a national vision with higher levels of clean energy ambition. The 2003 National Energy Policy was followed by the 2005 Renewable Energy Master Plan, the 2006 Renewable Energy Action Programme and the 2007 Nigerian Biofuel Policy and

incentives to initiate a domestic biofuel sector. In 2015 Nigeria launched the National Renewable Energy and Energy Efficiency Policy (NREEEP) and in 2016 it introduced the Rural Electrification Strategy and Implementation Plan (RESIP). Among these planning documents, RESIP was notable for shifting investment in the Nigerian renewables sector to being more centrally directed and less dependent on sub-national programmes, such as Lagos' Solar LED street lights project and Jigawa State's promotion of wind energy. State-led initiatives had been hampered by a lack of resources and co-ordination. In 2021 the Climate Change Act was passed and facilitated Nigeria's Energy Transition Plan in 2022, which contains the goal of reducing emissions to net zero by 2060.

Innovation context

In recent years Nigeria's innovation-related activities have increased, with participation from both public and private actors. The number of technology-focused start-ups and supportive government agencies has risen and Nigeria now ranks alongside Kenya, Egypt and South Africa as one of Africa's innovative economies. In 2023, 124 Nigerian technology start-ups received venture funding, compared with 62 in Kenya, 60 in South Africa and 46 in Egypt. These start-ups raised a combined UD 400 million. Overall, Nigeria was ranked only at 109 in the world for innovation performance in 2022, which was 11th in sub-Saharan Africa, below other lower middle-income countries in the region. One reason is Nigeria's relatively low public and private R&D expenditure as a share of GDP, which was 0.28% in 2019, lower than the sub-Saharan African and North African averages of 0.34% and 0.67%.

Most government funding for R&D and innovation in Nigeria is managed by the National Agency for Science and Engineering Infrastructure (NASENI), the National Office for Technology Acquisition and Promotion (NOTAP) and the Lagos State Employment Trust Fund (LSETF). On average, annual government expenditure on R&D was around USD 62 million between 2010 and 2019. Spending on education is higher and is set to account for 7.9% of the USD 34 billion 2024 national budget. With over 60% of the population under 30, a well-educated young workforce is a potential strength for innovation.

Energy innovation is less prominent in Nigeria than other technology areas. Two federally supported institutions are housed within universities: the National Centre for Energy Research and Development at the University of Nigeria was founded in 1982, and the Sokoto Energy Research Centre at Usmanu Danfodiyo University was launched in 2002 with support from the United Nations Educational, Scientific and Cultural Organisation (UNESCO). Compared with Kenya, Nigeria's efforts are more focused on financial and agricultural technologies. In 2023, two solar PV start-ups raised more capital in Kenya than all of Nigeria's start-ups in all sectors. However, some of the entrepreneurial activity in Nigeria's financial and digital

sectors has spilled over into clean energy. Together, Nigerian start-ups working on clean energy raised USD 2.3 million between 2020 and the first quarter of 2024. Mobile Power is an example of a Nigerian start-up active in this area. Digital technologies have also spilled over into the area of clean energy and "cold chains" for refrigerating produce. The start-ups ColdHubs and Fresh Direct Nigeria use solar-powered refrigeration to provide cold storage to farmers and small businesses, enabling them to preserve their produce and extend its shelf life. In these cases, access to reliable telecommunications infrastructure and predictable regulation was a more important prerequisite than access to physical energy infrastructure, such as power grids.

The case of innovation-oriented projects in the context of rural electrification

This case study considers how Nigeria's policies to promote solar PV in the country have gradually increased their coverage of R&D and other types of technology innovation support. The early plans and support measures did not give much attention to the innovation aspect, but by the time of the Climate Change Act in 2021 the idea of generating future economic prosperity through technology leadership and manufacturing had become a key policy objective. The story of policy development and the various initiatives launched to implement the policy targets highlights the importance of international co-operation, institutional empowerment and identifying market niches outside the established energy system in the Nigerian context. The results have been mixed, with a flourishing entrepreneurial culture that has developed to tackle energy challenges, but one that is hampered in part by a fragmented institutional setting and a disjointed project environment.

In Nigeria it took nearly a decade for the national vision for clean energy to translate into domestic clean energy innovation. Prior policy choices were strongly influenced by the need to address near-term objectives, such as tariff reform, privatisation and energy efficiency. However, by engaging in mini-grid projects for rural electrification and electric mobility programmes, it was possible to experiment and generate experiences that underpinned the inclusion of energy innovation goals in the Climate Change Act of 2021. The momentum had built up over the period since 2007, and the establishment of the Rural Electrification Agency contributed to the start of the construction of a USD 0.2 billion solar cell production plant in 2023 as a spin-off from NASENI.

First steps in solar energy innovation policy as part of Nigeria's renewable energy goals

The first key policy document to promote renewable energy in Nigeria (excluding large hydropower) was the 2003 National Energy Policy (NEP).[2] Its predecessor, the 2001 National Electric Power Implementation Policy, was drawn up by a federal committee tasked with addressing the unreliability of the distribution and transmission grids. While that policy focused primarily on grid-related issues, the NEP made the case for a rapid expansion of solar PV as a means of sustainably expanding the power sector to meet demand. However, it stopped short of including any specific support measures or targets.

In 2005 a further planning document was published to help implement the NEP. The Renewable Energy Master Plan (REMP) was partly funded by the United Nations Development Programme and set a goal for 10% of Nigeria's electricity supply to be from non-hydro renewable resources by 2025. At the time, all solar PV modules in Nigeria were imported from overseas, yet the REMP outlined a proposal for R&D spending in different renewable energy technology areas that would see Nigerian nairas (NGN) 187 million (USD 1.4 million) spent by the government in 2005-2007, NGN 350 million in 2008-2015 (USD 2.7 million) and NGN 690 million (USD 5.3 million) in 2016-2025.

The rationale for including R&D was stated as follows:

"If Nigeria is to optimally benefit from the application of RET [renewable energy technologies] it must have a credible R&D infrastructure for adapting and modifying imported RET to local conditions, set a stage for innovation and local manufacturing of RET, derive applicable business models and appropriate policies. R&D is also needed to address the social and cultural dimensions of deploying RET to secure their contribution to sustainable and participatory development."

The REMP proposed two new energy research centres, as well as co-operation with academia and attention to the commercialisation of any resulting innovation.

For solar PV, the R&D and training priorities included:

- Establish strong links between the two renewable energy research centres and PV research centres in Europe, America, India, China, Brazil, etc.
- Train engineers, technicians and other workers locally.
- R&D to ensure locally researched cells and modules have compatible efficiencies.

[2] Prior to this, the government had established the National Centre for Energy Research and Development (NCERD) at the University of Nigeria and the Sokoto Energy Research Centre (SERC) at the Usmanu Danfodiyo University in the early 1980s to research renewable energy technologies.

- Arrange exchange visits between Nigerian centres and overseas centres to determine state-of-the-art equipment for acquisition.
- Acquire research equipment.
- Source funding to install mini-module production plants.
- Initiate research on local raw materials to support the PV products industry.
- Collaborate on R&D between renewable energy research centres and engineering and physical science facilities at Nigerian universities.
- Organise training workshops, seminars and conferences at state, zonal and national levels for skills development.

In addition, the REMP suggested R&D priorities for geothermal energy, hydrogen energy, ocean energy, small hydropower and solar thermal energy. To help co-ordinate the research in new technology areas, a New Energy Research and Development Programme was proposed to prepare these energy sources to "play important roles in meeting the energy challenges of Nigeria in a post-fossil economy". In addition, a demonstration project for testing hybrid solar PV and wind and a national wind energy technology centre for training and maintenance were proposed, at a combined cost of NGN 800 million (USD 6.1 million).

While the inclusion of technology innovation goals and proposals represented a significant step forward, the REMP lacked legal status and more efforts were directed towards other NEP priorities than renewables-related R&D and training. By 2007 the electricity reforms led by the Ministry of Power were centred on the liberalisation and tariff reform agendas for the centralised grid. Implementation of the REMP struggled for funding and attention, the target of 0.8% of electricity from non-hydro renewables by 2007 was missed and the New Energy Research and Development Programme was never established. As the REMP had highlighted, a key barrier to the R&D programme was a lack of funds, something that the REMP proposed to address via international partnerships.

In parallel, a new area of energy policymaking for rural electrification emerged strongly. Nigeria's Rural Electrification Agency (REA) was established in 2007 to co-ordinate funds and projects. The REA is a quasi-autonomous entity within the Ministry of Power that has a mandate to pursue Nigeria's rural electrification agenda via grid extensions or off-grid resources.

From 2007 the REA worked towards the approval of the 2009 Rural Electrification Policy target to make reliable electricity available to 75% of the population (rural and urban) by 2020. The policy also enshrined the goal of 10% of electricity to be from non-hydro renewable sources by 2025. The combination of these two elements helped to institutionalise solar PV as an important means of meeting a widely supported social policy goal, and was instrumental to the progress that followed. To an extent, it benefited from some independence from issues concerning investment in the centralised grid.

As regards technology innovation, a new entity was established in 2011 within the science and engineering agency NASENI with the mandate to set up a solar PV manufacturing facility that would initially use imported raw materials and then transition to using only domestically sourced raw materials. In 2013 it was registered as a company called NASENI Solar Energy Limited (NSEL). However, while the government-funded 7.5 MW production plant was rapidly constructed, and subsequently expanded to 21 MW, it served mostly as a developmental facility. For comparison, the world's commercial solar PV cell factories were already much larger in 2011, with several above 1.5 GW of output per year, 200 times larger than the NASENI plant.

Overall, during this initial period of renewable energy policy development, energy technology innovation policy was boosted by Nigeria's formal systems for policy planning. The existence of the Energy Commission of Nigeria as a body responsible for planning, and the regular revisiting of planning documents for the short and medium term, were key elements in the articulation of a role for renewable energy in Nigeria, and the need for associated R&D. The familiarity with target-setting and planning documents helps explain the government's choices with respect to solar PV during this period. However, the lack of institutional capacity to manage longer-term policy priorities prevented plans from being implemented that did not align with the near-term visions for the centralised power grid and retail market. This situation began to change with the establishment of the REA, which could take a longer-term view of the role of solar PV and also take responsibility for its delivery.

A focus on technologies for rural electrification under the 2016 Rural Electrification Strategy and Plan

The next major institutional step towards the development of a sustainable solar PV sector in Nigeria was the 2015 NREEEP,[3] which was closely followed by the 2016 RESIP. The NREEEP had a list of incentives intended to support producers, manufacturers and importers of solar PV goods and services. It stipulated that manufacturers of solar PV equipment were entitled to interest-free capital relief of 50% on initial investments. Despite the stipulated support for manufacturing, only the biofuels section of the NREEEP had clear language on and a target for R&D spending, stating that an R&D fund would be established "to encourage synergy between the private and public sectors in R&D in which all biofuel companies shall contribute 0.25% of their revenue for research in feedstock production, local technology development and improved farming practices".

[3] The NREEEP was complemented by a National Renewable Energy Action Plan (NREAP) and a National Energy Efficiency Action Plan (NEEAP).

The NREEEP also provided a menu of authorised policy instruments that could be used to give preference to renewable energy in Nigeria, including:

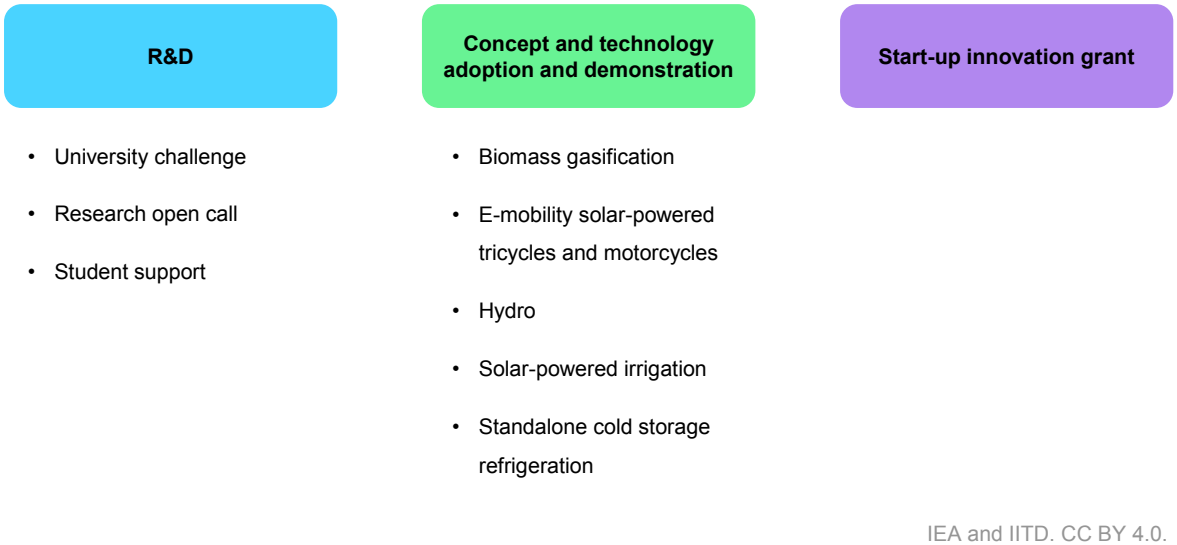
- Voluntary or mandatory renewable portfolio standards.
- Auctions or bidding rounds for independent power producers.
- Disclosure requirements to increase consumer information.
- Capital grants and tax exemptions.
- Production tax credits for electricity generation.
- Feed-in tariffs or net metering for small-scale generators.
- A public benefits fund to allocate a percentage of tariff revenue to support on- and off-grid projects.

However, while the NREEEP established the basis for government agencies to create a market for renewable energy technologies, it was the RESIP that pushed forward the deployment most strongly. By promoting a least-cost approach to the electrification of rural communities, along with a Rural Electrification Fund to stimulate uptake, solar PV was immediately prioritised.[4] The RESIP established an interim target to add 1 million connections and 800 MW of mini-grid capacity (of which 80% to be solar PV) in rural communities by 2020. In addition, the RESIP contained measures for improving R&D in the sector and reducing the fiscal barriers to private sector participation. For instance, one of the core policy themes of the RESIP was capacity building for the execution of projects by local Nigerian companies by improving their understanding of and qualification for developing and running renewable energy projects and encouraging these actors to play a more active role in the renewables value chain (materials, manufacture, construction and operation of the assets). Among several instruments for supporting the deployment of solar PV in different types of communities, the Energizing Education Programme, launched in 2019, has a significant component related to technical training in the solar PV area, including a dedicated programme for women.

The R&D and localisation goal of the RESIP has been supported through performance-based grants, a minimum subsidy tender, an output based fund and a market scale-up challenge fund for qualified renewables projects. The REA proposed a Research and Innovation Hub in 2021 to provide grants for R&D and innovation by start-ups (Figure 11.3). While the student support element is the only one established to date, the innovation hub idea signalled a change in ambition for the REA in this area. Notably, it considered not only supply-side technologies for off-grid renewables, but also energy-efficient appliances and solar-powered end-use applications such as irrigation and electric mobility.

[4] This was complemented by a Nigerian Sovereign Green Bond, the first certified green bond in Africa, issued for USD 250 million in 2017 to provide foreign exchange support to solar PV importers.

Figure 11.3 The structure of the Research and Innovation Hub proposed by the REA in 2021



Source: REA (2021) Unveiling the REF research and innovation hub.

The RESIP had a catalytic effect on the levels of activity around solar PV in Nigeria. Because it focused on a socially important topic that could be accomplished via multiple, parallel, independent projects, it could attract considerable financial support from international donors. Between 2016 and 2020 a wide range of initiatives were launched with international partners, many of which included an innovation dimension (Table 11.1).

Table 11.1 Selected rural electrification projects in Nigeria with international partners

Partners	Project	Year started	Financial contribution (USD million)	Technology innovation contribution
African Development Bank and Shell	Nigeria Energy Access Fund	2019	15	Equity/quasi-equity investments in small- to medium-scale sustainable energy projects that have measurable climate-positive and energy access impact.

Partners	Project	Year started	Financial contribution (USD million)	Technology innovation contribution
African Development Bank/ World Bank	Nigeria Electrification Project	2019	550	Technical and financial support to enhance project delivery and management to strengthen the off-grid ecosystem. So far the project has delivered 120 mini-grids and 1.4 million solar home system connections.
Germany and the European Union	Nigerian Energy Support Programme I, II and III (including Interconnected Mini-grid Acceleration Scheme)	2016*	61	Technical assistance to mini-grid developers and tenders for registered mini-grid developers in Nigeria to install mini-grid capacity.
Rockefeller Foundation, The Global Energy Alliance for People and Planet, and Shell	All On Hub	2020	(Has invested USD 0.24 million in 24 start-ups in addition to providing prizes and grants)	Support to nascent ventures in the Nigerian energy sector, including grants, workspace, incubation, technical assistance and business advice.
United Kingdom	Solar Nigeria Programme	2014	100	Works with 40 private sector actors within the solar value chain (manufacturers, installers, and financers). Offers market scale-up grants.

Partners	Project	Year started	Financial contribution (USD million)	Technology innovation contribution
United States (US African Development Foundation) and Shell	Expand the solar panel assembly capacity of Auxano Solar Nigeria Ltd.	2020	1.5	Auxano has now trained 800 people in solar assembly, distribution and aftersales services.
World Bank	Technical assistance	2018	27	Technical assistance to public and private sector stakeholders, including the REA and Ministry of Power to build a sustainable framework for scaling up rural electrification.
World Bank	Market Scale-Up Challenge Fund	2019	15	Lump sum grants in support of strong business plans that have other co-funding sources for remaining 70-80% of scale-up funding needs.
World Bank and African Development Bank	Energizing Education Programme	2017	310	Installation of mini-grids at universities and creation of renewable energy training centres for students' innovation. Includes training for female students during the construction phase.

Partners	Project	Year started	Financial contribution (USD million)	Technology innovation contribution
World Bank and Climate-KIC	Nigeria Climate Innovation Centre	2018	Not known	An independent company that aims to accelerate energy access in Nigeria by supporting early-stage enterprise development and increasing the investable pipeline of local off-grid solar companies.

* Phase I of NESP ran from 2013 to 2018.

The variety of programmes launched with international partners in Nigeria has helped to build domestic expertise in the public and private sectors. Exposure to a range of partners has provided exposure to a diversity of technologies, processes and experiences. Importantly, most of the projects and initiatives share a consistent focus: the use of solar PV and mini-grids to create entirely new markets for electricity in rural areas. In a context where a single model solution does not yet exist globally, the importance of technology to overcome arising challenges, as well as the general absence of incumbent solar firms, ensured a focus on technology innovation and capacity building in most programmes.

Another public instrument used to incentivise corporate spending on R&D is the national local content policy in the power sector, which promotes the utilisation of local human and material resources across the electricity system's value chain. The Nigerian Content Development and Enforcement Bill 2020 has emerged as a product of the local content policy and aims to create 250 000 energy sector jobs and localise solar manufacturing. The markets for mini-grids and solar home systems have a combined potential annual revenue of USD 6 billion. To support investors in identifying potential market, the REA under the NEP has identified 10 000 sites for mini-grid development.

Alongside the various initiatives related to rural electrification, the Nigerian government also created market incentives to implement the NREEEP and assist the scale-up of the solar PV market in Nigeria. A feed-in-tariff was put in place for grid-connected renewables in 2016 and it was signalled that distribution companies would be set renewables procurement targets and penalised for not

meeting them.[5] In addition, in 2016 the Nigerian Electricity Regulatory Commission published rules for mini-grid operators that made them eligible for predictable multi-year tariffs and compensation if the grid is later extended to the same territory. To assist market creation, the World Bank and the REA Nigerian Electrification Project provided USD 60 million as grants to private companies of different sizes to bridge the cost gap between solar PV mini-grid systems and other non-renewable electricity sources.

Examining the background to this policy approach, it is evident that the REA was constrained by the lack of domestic public finance and limited political capital compared to institutions tasked with other major economic policy reforms. In parallel, its access to international support was elevated by the close alignment of the RESIP with development and sustainability goals. The global agenda around rural electrification via renewable energy had gathered momentum by the time of the signing of the Paris Agreement and UN Sustainable Development Goals, both in 2015. However, one potential downside of an approach reliant on multiple programmes with different partners – rather than a co-ordinated policy package steered by the government – can be a fragmentation of efforts or lack of co-ordination among donors and planning bodies. In the case of Nigeria, one element that helped avoid fragmentation of efforts and inter-institutional competition was the central presence of the REA as a national planning and co-ordination body.

Current status: Prioritisation within the 2021 Climate Change Act, local and foreign direct investment in manufacturing

In 2024 solar PV and clean energy technology innovation occupy more central positions in Nigerian policymaking. Their impact on total energy supply and economic indicators remains modest, but they are seen as integral parts of the future economy. One example of how the successful experiences with rural electrification projects have shaped government thinking is the support package assembled by the Central Bank of Nigeria in mid-2020 in response to the financial impacts of the Covid-19 pandemic: it included concessional loans for companies engaged in “manufacturing of solar components”, “assembly of solar components”, “maintenance of solar home systems and mini grid equipment”, “solar component R&D” and “any other off-grid solar value chain activity”. The rationale given was an economic one: “pay-as-you-go (PAYG) off-grid technologies… will create a USD 2 billion annual market opportunity [and, together with] the roll-out of 5 million new solar-based connections in communities that are not grid connected… this program is expected to generate an additional NGN 7 billion [USD 18 million] increase in tax revenues per annum and

[5] Renewable portfolio standards for renewables from independent power producers connected to the distribution grid were enacted in early 2024 and set separately for each distribution company at around 5% of contracted capacity for the following year.

USD 10 million in annual import substitution." Also in 2020, the Bank of Industry made USD 15 million available to provide low-cost debt to solar-related projects.

A year after this central bank intervention, Nigeria's national vision for clean energy was propelled into a new phase by the international consensus around the target of achieving net zero CO_2 emissions. Like many other countries in 2021, Nigeria pledged to achieve net zero emissions and set a date of 2060. To accompany and implement this pledge it published a Climate Change Policy, an Energy Transition Plan and a Climate Change Act. In these documents, energy technology innovation is given much greater prominence than in previous long-term energy plans. Among the ten policy goals of the Climate Change Policy, the third is to promote "scientific research, technology and innovations to address the challenges of climate change" to "pursue an alternative and sustainable path to industrialisation that takes advantage of innovations, technologies and business models for improved energy efficiency in the industrial sector". The document further commits to "support financial services entities with appropriate policies to play an adequate role of providing the financial and de-risking products needed to fund innovations necessary for climate actions". The Energy Transition Plan estimates that, if successfully implemented, the 2060 goal will result in the creation of up to 340 000 jobs by 2030 and up to 840 000 jobs by 2060, and will require innovation for cost reductions, local technology adaptation and skills development.

However, barriers to clean energy innovation remain in Nigeria beyond the limitations to government funds. The cost of capital for innovative companies in the energy sector is very high, with few alternatives to bank loans at 27-30% interest rates, a level that makes early-stage risk-taking impossible for hardware developers. While some dedicated sources of capital exist to support companies to implement the RESIP goals – such as the Bank of Industry Solar Energy Fund, the central bank's Solar Connection Intervention Facility and equity and debt financing from All On – they are limited in scale and scope. Innovators often rely on grants from overseas governments or equity from overseas sources. A downside of this is that some start-ups locate their headquarters abroad to be closer to sources of finance and foreign partners that can help them access these funds. For example, Lumos Global, a developer of solar finance solutions that has raised over USD 100 million including from All On, is now headquartered in Amsterdam. Koolboks, a start-up inventor of an efficient off-grid refrigerator for Africa, is headquartered in France.

Domestic start-ups can be valuable champions of renewable energy policy development because, as they grow, they bring a credible private sector voice to the political process. Auxano Solar and Lumos Global have played this role in Nigeria. Other related start-ups founded in recent years include Rensource, which uses digital technologies to optimise solar PV installations, Greenage Technologies, a maker of home solar products including inverters, Salpha Energy,

a developer of integrated solar kits for off-grid use, and Powerstove Energy, a manufacturer of cleaner cooking equipment.

The ability of innovative companies in the solar manufacturing arena to scale up quickly is hampered by several additional factors. Nigeria imports the vast majority of the solar PV equipment it installs and its value has been estimated at over USD 518 million between 2018 and 2021, with panels being nearly 50% of this. Auxano, Blue Camel and other assemblers meet less than 20% of demand. This is despite several measures in place to support local manufacturing. In 2017 the government granted solar panel manufacturing Pioneer Status, which exempts the sector from corporate income tax for three to five years. There are also tariffs that disfavour imports. In 2019 the Nigerian Customs Service reclassified solar panels from a class that has no associated duty (85414000), to one for direct current generators (85013300), which carries a 5% duty. A 5% value-added tax on imported solar panels with diodes was also introduced, along with a 20% import tariff on batteries. Additionally, in 2020 the government proposed a Nigerian Content Development and Enforcement Bill.[6] However, rather than stimulate domestic manufacturing, this could make solar installations less profitable, reducing the uptake of renewable energy in Nigeria. One supportive factor is that the central bank provides foreign exchange to importers of solar products at the official government rate, which is advantageous.

Two promising developments in 2023 may improve the outlook further. In early 2023 China Great Wall Industry Corporation co-invested with the government's science and engineering agency to construct a solar PV cell factory for NASENI costing USD 0.2 billion. All but 15% of the cost will be covered by finance from the Bank of China. Additional investments with Chinese entities in a transformer production plant and high-voltage testing facility are planned. This total investment builds on over a decade of work since the establishment of NSEL by NASENI, during which time it has patented several technologies, including a mini solar generator and a 1.5 kVA "plug 'n' play" solar home system. NASENI has deployed 780 solar-powered streetlights and 850 kW of generation capacity. It has run an educational programme for schools and trained 150 people in technical capacity for solar PV design, installation and entrepreneurship. In addition to solar PV it has also manufactured small hydro turbines. The investment from China has the potential to transform the experience from a very small operation into a competitive player in Africa's solar market. The other notable development was the announcement in late 2023 of the Distributed Access through Renewable Energy Scale-up (DARES) programme, which could lift the solar PV market in Nigeria to

[6] The bill is not yet enacted, but would extend local content requirements to sectors other than oil and gas, requiring at least 40% of public works to be contracted to Nigerian companies, and create surcharges of 2-3% on all contracts in seven sectors, including the power sector. An additional part of the proposal is to require Nigerian companies in these sectors to domicile 5% of their net profits with the Central Bank of Nigeria for R&D, of which half would be allocated by the government to Nigerian universities and research institutions, and half would be spent by the company and be tax deductible.

a new level. It represents over USD 1.1 billion of combined funds from the World Bank, Japan International Cooperation Agency, Global Energy Alliance for People and Planet, International Finance Corporation and SE4ALL

Findings

After two decades of policymaking for renewable electricity, Nigeria could be well placed to take advantage of the economic opportunities offered by innovation in the rapidly growing solar PV market. Its innovation ecosystem has developed markedly in adjacent sectors such as finance and communications, and a series of programmes on rural electrification with international partners have helped this to expand into the clean energy domain. Nigeria's workforce is young and underemployed, and several private and public universities have strengthened and expanded their curricula in the area of renewable energy technologies. Recently, investment in the solar PV supply chain and in Nigerian energy start-ups has ticked up. Understanding how Nigeria reached this point and the strengths of its policy pathway provides valuable lessons that can inform further progress and also other countries or sectors facing similar challenges.

The case study shows the importance of goal setting and planning to pursue multiple policy objectives simultaneously. The existence in Nigeria of a formal planning body in the form of the Energy Commission of Nigeria was important for establishing common expectations. However, the plans for renewable energy, including R&D, were unable to be implemented as initially envisaged until there was strong alignment with the national policy vision. In the case of solar PV in Nigeria, the catalytic factor was alignment with a global vision, first for rural electrification and then for net zero emissions, which the financial donor community could support. This international finance was critical for overcoming a shortage of public funds for a policy objective that was not the central concern of the Ministry of Power in the 2005 to 2015 period.

A further insight from the case study relates to the co-ordination value of having a nodal government agency responsible for delivering a challenging and innovation-related policy goal. The REA provided continuity and expertise during a period of rapid policy design related to the RESIP and NREEEP, as well as during the design and execution of multiple programmes with international partners. The REA has helped maintain a level of institutional co-ordination, but has not entirely offset a more general fragmentation of institutional capacity. While the Ministry of Power controls the formal policy-making process related to electricity, adjacent projects and initiatives have been launched outside its formal channels. For example, the agriculture and environment ministries have been involved in new bioenergy programmes, and international donors have sometimes proposed their preferred projects with different stakeholders. Among these stakeholders are state and local governments, which play a key role in implementation, including for

technology innovation via universities, but are not always well integrated into the policy design phase. There is therefore scope to foster more linkages between institutions to verify that planning targets are achievable and to ensure that policy instruments are designed to complement and reinforce each other.

For countries without extensive financial resources for long-term R&D, it is important to build on existing skills and identify promising technology niches that have synergies. In Nigeria this has been the case with knowledge spillovers from the innovation community around financial technology ("fintech"). Pay-as-you-go (PAYG) systems for solar PV and energy storage are popular in Nigeria as their microfinancing model accommodates the wage structure of most low-income earners, particularly those in the informal sector. This enables households and businesses to access solar power solutions more easily and it draws directly on local entrepreneurship in adjacent finance and digital sectors. Governments can enhance innovation outcomes by supporting these enabling conditions in adjacent parts of the economy, as well as links between sectors.

However, it has been more difficult to foster businesses for the large-scale manufacture of renewable energy components and equipment. The efforts of NASENI did not build on an existing high-tech manufacturing base. Despite the imposition of import tariffs and support from the national agency tasked with bridging science, technology and manufacturing, NSEL struggled to scale up between 2013 and 2023. As in many other EMDEs, significant headwinds face projects for building new and advanced technology manufacturing from scratch without international partners if there is a lack of transferrable knowledge and skills from similar sectors. In Nigeria, the inward investment by a Chinese firm in 2023 to partner with NASENI has potentially kick-started a solar PV production sector, but the extent to which NASENI's past research and personnel will be leveraged to create additional value for the joint venture is unclear. The government has an opportunity to ensure that local staff receive high-quality technical training and to support the conditions for entrepreneurship and additional investments in complementary and innovative activities alongside the new factory.