SOLAR POWER FOR RESILIENT HEALTHCARE SYSTEMS IN NIGERIA: REGULATORY, FINANCIAL AND ORGANIZATIONAL OPTIONS FOR SUSTAINABLE BUSINESS MODELS

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Introduction

When the COVID-19 pandemic struck in February 2020, Nigeria's health care systems were already in a poor form resulting from decades of neglect.[1] The health care systems were in need of wholesale reform and investment. The Global Healthcare Access and Quality Index ranked Nigeria 142 out of 195 nations, based on deaths from 32 factors, which would not have been fatal

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given timely and effective healthcare, between 1990 and 2016.[2] The reasons for the health infrastructural deficit in Nigeria range from low governmental expenditure to shortage of healthcare workers, lack of modern medical equipment, corruption, medical tourism, and an epileptic power supply.[3] The pandemic has placed an extra burden on medical facilities for diagnostics, therapeutics, and critical equipment such as oxygen and ventilators.[4] Additionally, with the onset of the vaccination programs in March 2021, strengthening the cold chain capacity has become a priority to ensure vaccine refrigeration throughout distribution and storage.[5]

Invariably, healthcare specialists have deemed the COVID-19 crisis a wake-up call to revitalize the Nigerian health system.[6] Among the improvements triggered by the COVID-19 crisis, the electrification of medical facilities through renewable energy (RE) has emerged as a rapid and affordable solution for access to health, particularly for the poorest and most remote/rural sectors of the population.[7] Such views advance the links between Sustainable Development Goal (SDG) 7 (access to affordable, reliable, sustainable, and modern energy) and SDG 3 (good health and well-being for all) in the 2030 Agenda for Sustainable Development adopted by the United Nations (UN) in 2015 to prioritize and optimize energy solutions for health access gaps and needs.

A 2013 study estimated that only 28% of healthcare facilities in six sub-Saharan African countries (Nigeria, Ethiopia, Tanzania, Kenya, Uganda, and Ghana) have access to reliable electricity.[8] RE provides healthcare facilities a practical alternative for securing reliable and uninterrupted electricity to water pumps, medical devices, computer systems, and other necessities.[9] Additionally, it contributes to climate change mitigation through reduction in greenhouse gas emissions in a country over-reliant on fossil fuels. Rural dwellers particularly struggle with energy deprivation and blackouts due to unaffordable generators powered by petrol or diesel.[10] It is estimated that electrifying healthcare facilities in Sub-Saharan Africa with decentralized RE technologies can reduce the travel time of the population to access such facilities.[11] Ultimately, the proximity of healthcare facilities has a significant impact on health outcomes across the population.[12]

In 2020, initiatives for the electrification of health facilities integrated national strategies to strengthen Nigeria's response to COVID-19. Such initiatives included, among others, All On's *COVID-19 Solar Relief Fund* installations and the Rural Electrification Agency's (REA) *COVID-19 and Beyond*, a component of the *Nigeria Electrification Project (NEP)* on Solar Hybrid Mini-Grids—which is currently funded by the World Bank.[13] The REA is the implementation agency of the Federal Ministry of Power in charge of the electrification of unserved and underserved communities across Nigeria. These initiatives focus on building mini-grids and standalone solar energy infrastructure coupled with battery storage as technical solutions to increase the efficiency of medical services. Decentralized solutions can function separately from the national grid and reach locations where service is insufficient, or where the grid is not available, as is often the case in rural and remote areas.

Nevertheless, healthcare facilities lack the resources to deliver essential medical services and are subject to ongoing uncertainties impacting their ability to fund RE costs.[14] Funding for powering primary healthcare facilities (PHCs) in most rural communities and capital cities in Nigeria is meagre and limited. Additionally, the healthcare services provided in PHCs generate paltry, irregular revenue source. Their budget is consistently insufficient to pay for energy services, equipment maintenance, replacement of solar batteries, and related costs outside of the health facilities' core functions.

This article attempts to answer a critical question: what are the business models for sustainably powering PHCs in Nigeria? In sum, the problems are as follows:

(i) PHCs lack the initial capital investment for solar power.
(ii) PHCs need regular funding to maintain new and existing solar power facilities.
(iii) PHCs need sustainable energy to deliver essential healthcare services to low-income and rural households.

To address the above problems, first, this article provides a brief description of the mixed-method design, followed by a background of the Nigerian Law and Policy's RE incentives. The results are presented in two ways. First, the financial analysis suggests bankable options for sustainably powering PHCs based on simulated scenarios. This analysis is complemented by advancing organizational strategies to ensure the sustainability of the business models. In conclusion, the bankable options for the energy supply of PHCs using a Luminous or lithium battery require a careful arrangement of allocation of costs and risks among the government, financial institutions, and donors. As PHCs have a limited budget for their basic operational needs, it is unlikely that they can pay for operation and maintenance costs and battery replacement in the long term. Consequently, the solar infrastructure risk of becoming inoperative. One of the options to ensure smooth functioning of the system is to include the PHCs inside oversized structures such as university teaching hospitals, or use small and medium-sized businesses with community development interests in the surrounding areas and a better source of subvention or revenue. In Nigeria, the REA is in a strategic position to coordinate initiatives in the electrification of healthcare facilities, with a leading role in integrating the health and energy sectors.

Methodology

This research applied a mixed-method design, where data was primarily collected using individual qualitative interviews and integrated with financial analysis, law and policy analysis, and literature review. It began with selecting a group of energy experts in Nigeria drawn from academia, government, business, and consultancy, including lawyers, economists, and engineers. The researchers interacted with these selected stakeholders using virtual online interviews and administered questionnaires. The experts provided perspectives on achieving regulatory and financial goals in Nigeria to provide a funding pool that will cover healthcare facilities' RE costs in the long term.

The interview results were organized and analyzed using the well-established thematic analysis technique, following specific procedures to interpret and extract meaning from the collected data.[15] Accordingly, some themes concerning the research question have emerged, which highlight a set of assumptions underpinning the problem statement, detailed as follows: first, the healthcare facilities lack sufficient revenue to maintain the RE infrastructure. While there have been increasing opportunities to fund infrastructure equipment deployment, the healthcare facilities need continuous funds and skilled personnel to carry on operation and maintenance in the long term. Some business models of sustainable RE for healthcare facilities in Nigeria include allocating RE costs to the government and donors or the institutions and businesses involved in healthcare facilities. Two examples of the latter are the integration of PHCs into currently functioning public institutions, such as university teaching hospitals, and the allocation of RE costs to small and medium-sized businesses with commercial interests in the area where the PHC is located.

The Advisory Board (AB) members have reviewed the interview results, adding input from their own experiences. The AB was composed of leadership stakeholders with expert knowledge of healthcare facilities electrification both in Nigeria and internationally. Based on the results, the research question regarding sustainable RE business models for healthcare facilities consists of two derived inquiries concerning the allocation of financial risks and governance aspects. The first question concerns the bankable options for ensuring energy supply to PHCs and focuses on financial analysis. For this section, scenarios were drawn considering assumptions of the PHCs' energy system load profiles for either urban or rural areas in Nigeria. These assumptions relied on official data analyzed by key studies and were complemented by a mathematical model of the repayment of costs derived from the PMT function in Microsoft Excel.

The second question explores organizational strategies to ensure the long-term sustainability of the RE investments in healthcare facilities, including collaborations and coordination between the energy and health sectors and the participation of the private sector. The results are based on the findings from the interviews and a review of legal and policy documents, official reports/statements, and journal articles and books.

Background: Critical Views on Nigerian Law & Policy's Incentives for RE

The main RE sources in Nigeria are water (hydro), solar, biomass, and wind, with the government taking targeted steps to pursue a bespoke RE policy attuned to Nigeria's realities and complementary to other energy sources.[16] In a bid to deliver clean, cost-effective electricity the Nigerian regulators/policy makers[17] have introduced legislation, policies, and guidelines on RE to promote electricity generation and distribution (Table 1). Together, these laws and policies create a framework for attracting finance, deepening access to electricity, and promoting RE as an alternative energy source.

Table 1
NIGERIAN LAW & POLICY INSTRUMENTS DIRECTLY IMPACTING RE DEVELOPMENT AND IMPLEMENTATION

Legislation & Policy	**Objectives**
2004 Environmental Impact Assessment Act	Setting out the general principles, procedures, and methods of environmental impact assessment in various sectors, including for the power generating company or developer to obtain projects permission or license
2005 Electricity Power Sector Reform (EPSR) Act	Restructuring the power sector, including the creation of the Nigerian Electricity Regulatory Commission (NERC), unbundling of the Power Holding company, and privatization and licensing of electricity generation and distribution companies
2005 Renewable Energy Master Plan (REMP)	Increasing the supply of renewable electricity from 13% of total electricity generation in 2015 to 23% in 2025 and 36% by 2030
2015 NERC Regulations for Feed-In-Tariffs for Renewable Energy Sourced in Nigeria (REFIT Regulations)	Providing a tariff framework for renewable sources, including establishing that electricity distribution companies shall, as a matter of priority, purchase 50% of the RE electricity capacity limit established by regulation
2015 Nigerian Renewable Energy and Energy Efficiency Policy (NREEEP)	Setting a framework for RE and energy efficiency by removing economic, regulatory, or institutional disadvantages and providing a conducive political environment for investments (e.g., tax incentives for manufacturers and importers)
2017 NERC Regulations for Mini-Grid Systems	Creating a framework for the establishment and operation of mini-grids (i.e., limited to distributed power of less than 100 kW up to 1 MW), to accelerate electrification of unserved and underserved areas

The Nigerian law can support investment in the RE sector through the following interventions:

(a) Double taxation treaties
(b) Bilateral investment treaties
(c) Targeted tax incentives and subsidies to alleviate upfront RE project costs such as—
  (i) Pioneer status: a company granted pioneer status is entitled to a 100% tax holiday for seven years if the company is established in an economically disadvantaged area in Nigeria
  (ii) Tax relief for investment in research and development
  (iii) Incentives for companies that provide essential infrastructure that ought to be provided by the government
  (iv) Duty free incentives for five years for importers of energy saving equipment
  (v) Low interest loans from various power sector intervention funds
(d) Anti-expropriation: Section 44, 1999 Constitution, Section 25, Nigerian Investment Promotion Commission Act

There is also a commercial objective for foreign investors to invest in Nigerian RE. They can be accommodated under the RE Feed-in Tariff (REFIT), denominated in US dollars, and obtain revenue from the RE plant over a 20-year period. However, the instability of the Naira and the rate of inflation make it difficult to attract local commercial players. The most likely outcome is that such projects will continue to be driven by governmental agencies.

From a regulatory perspective, a number of challenges have slowed the success of Nigeria's RE generation and distribution, including multiple and overlapping regulatory and policy initiatives, lack of clarity around renewals of licensing permits for RE projects, liquidity issues caused partly by incoherent regulations, lack of political will to implement existing regulations, lack of a clear incentive framework for the RE sector, and the high cost of implementing RE projects.[18]

It is important for the government to demonstrate its commitment to increasing the adoption of RE by creating an appropriate legal and commercial environment. While reviewing the legal barriers slowing the extensive adoption of RE in Nigeria, P. Oniemola suggests that the existing legal framework does not position RE at a competitive advantage.[19] Oniemola further urges that the legal framework be redirected by ensuring RE is prioritized from a legal standpoint to facilitate the uptake of RE investment. The EPSR Act should be amended to provide RE with a priority access to the electricity network.

F. Adeniyi evaluated the constraints of RE projects in Nigeria, suggesting that the underperformance of the Nigeria Electricity Supply Industry (NESI) is caused by the short-term conduct of NESI actors, creating constraints for long-term RE investments in Nigeria.[20] The structure of the NESI inhibits RE deployment in

Nigeria via the conduct of its actors, underperformance, and the resulting inadequate intervention of the Nigerian government. It is possible for this challenge to be met by amending the EPSR Act to allow for the grant of a license for RE projects for a long term of around 15–20 years by NERC. In addition, the application of the master plan for RE needs to be undertaken with vigor by ensuring adequate modification as may be appropriate to fit with existing regulations on RE.[21] The government must demonstrate its commitment to RE adoption by encouraging a coordinated response by all its agencies, providing subsidies and funding support to promote the implementation of its RE plan within the regulatory framework. For example, the existing policies fail to outline specific steps for promoting development of solar technology.

In addition, it will be beneficial if policies and regulations around RE development and implementation take into account appropriate business models that promote the implementation of RE projects.[22] RE projects will attract favorable financing terms if they align with workable business models and it is clear to project participants that existing government regulatory instruments will be applied consistently and that licenses, approval processes, and inspections will be undertaken speedily. Also, the regulators and other Government Agencies including the Standards Organisation of Nigeria (SON), NERC, Customs, Federal Ministry of Power, and Federal Ministry of Finance need to work together to continually develop and facilitate appropriate RE standards in a transparent manner.

Results

Financial Analysis: Bankable Options for Energy Supply to PHCs *Conceptual Framework of Options:* Though the government makes budgetary provisions for settling PHCs' electricity tariffs and other utility charges, funds are not regularly disbursed to PHCs. A study of 60 PHCs showed that the facilities in Abuja received only 10% of the ₦9.45 million allocated in the 2017 budget.[23] Three key variables relevant to developing bankable options for powering PHCs are (a) initial capital investment, (b) project funding/loan repayment source (if necessary), and (c) sustainable funding for maintaining the solar power plant.

Presuming that the initial capital investment is borne by the government, development partners, and energy developers, two vital issues to address would be: how to ensure the repayment of the developer's portion of the investment and how to secure sustainable funding for maintaining the solar power plant. Within this context, the financial analysis of some options for sustainably powering PHCs are undertaken in this section. The section also addresses each option highlighting the capital expenditure (CAPEX) and operating expenditure (OPEX) per kWh computed as a ratio of cost to total lifetime energy production. Although levelized cost of energy (LCOE) may seem appropriate, it is not applied here because the focus is on the same energy source/technology: solar.

Analysis of Bankable Options: The options for PHC energy supply are simulated under two possible scenarios, namely the Luminous battery and the lithium battery, based on bills of quantities from energy developers as well as details of the PHCs' energy situation and solar projects undertaken in the Federal Capital Territory, Abuja, Nigeria. Some of the projects studied were undertaken as corporate social responsibility initiatives by Vaya Energy.[24] The hybrid option of solar and diesel generator systems is not considered as it is unsustainable due to diesel supply costs in rural communities and also the resulting pollution.[25]

At the outset, assumptions about rural PHCs are made based on available data from urban PHCs. The two scenarios are simulated on the premise that the average urban PHC expends between ₦3,500 and ₦19,000 (per month) on electricity charges, as well as between ₦9,000 and ₦29,000 (per month) on diesel/petrol for fueling generator plants.[26] Given this context, it is arguable that the urban PHCs that spend more on fuel use and less on grid electricity. So, it can be ascertained that most urban PHCs spend at least between ₦28,000 and ₦32,500 on electricity tariffs and the fueling of generators (excluding maintenance costs). Due to differences in their energy requirements,[27] it is reasonable to posit that rural PHCs could spend about half as much as urban PHCs—between ₦14,000 and ₦16,250 every month.

Furthermore, it is assumed that with solar energy supply, each PHC is powered sufficiently to provide additional healthcare services that can generate surplus revenue in addition to receiving external subventions. Consequently, the simulation here suggests that the existing energy expenses of PHCs, though adequate, can be reallocated from fossil fuels (petrol and diesel) to solar energy with some savings and a significant reduction in greenhouse gas emissions.

A. Luminous Battery Option: A 2.5kVA solar power system has an estimated initial cost of ₦990,000 with two 24-volt Luminous batteries. Therefore, the capacity of the solar power system is considerably higher than the average daily electricity consumption and peak load of rural PHCs[28]—electricity demand assumptions are presented in Table 2. Understandably, there are differences in daily energy load profiles of PHCs (rural and urban), but Table 2 has been adapted and presented here for illustrative purposes.

Assumptions of Luminous Battery (Scenario 1): The uniqueness of this Scenario lies in splitting financial responsibilities and risks for the sustainability of standalone solar energy projects for rural PHCs. Moreover, it presents energy developers with opportunities for after-sales services to PHCs, thereby making it a potentially sustainable business option from the perspective of the entire solar industry.

Specifically, for this option, as Table 3 highlights, the following risk allocations are conceivable:

(i) the CAPEX will be borne partly or entirely by the Federal Government (Ministry of Power or the REA),

Table 2
RURAL PHC LOAD PROFILE TO BE MET WITH 2000 WATT SOLAR POWER SYSTEM[a]

S/no	Energy Appliance	Qty	Power (Watts)	Total (Watts)	Total Hours/day	Total Energy (kWh/day)
Medical Devices						
1	Refrigerator-Vaccine	1	60	60	10	0.60
2	Television	1	50	50	7	0.35
3	Microscope	1	20	20	6	0.12
4	DVD Player	1	60	60	5	0.30
5	Decoder	1	40	40	8	0.32
Lights						
6	Interior Lighting (a)	3	60	180	24	4.32
7	Interior Lighting (b)	3	60	180	14	2.52
8	Security Lighting	4	60	240	13	3.12
Clinical Appliances						
9	General Purpose Refrigerator	1	300	300	5	1.50
Infrastructure						
10	Radio	1	30	30	2	0.06
11	Desktop Computer	1	230	230	4	0.92
12	Ceiling Fan	3	75	225	13	2.93
13	Phone Charger	1	2	2	8	0.01

[a]Inverter Rating: 24V/2000 WATTS/2.3/2.5KVA.

Source: Adapted by authors from V. A. Ani, "Powering Primary Healthcare Centres with Clean Energy Source," *Renewable Energy and Environmental Sustainability*, vol. 6 (2021), pp. 1–16, and updated for Rural PHCs.

(ii) the CAPEX will be partly or fully sponsored by development partners, international donors through aid as a developmental intervention by the Federal or State Government,

(iii) the OPEX will be borne by each PHC using subventions received from the government or commercial interests. Its viable implementation requires creating a maintenance fund/plan (from the onset) at conceptualization or during the initiation of the solar energy project. As such, the cost of maintaining the solar energy system and replacing the batteries in the seventh year will be the primary responsibility of the PHCs to ensure that the energy asset is sustainably used. However, a key issue is the uncertainty, irregularity, and riskiness of subventions/revenues to rural PHCs.

B. Lithium Battery Option: The second scenario is proposed with a standalone 2.5kVA solar power system using lithium batteries for a capital outlay of

Table 3
ASSUMPTIONS OF LUMINOUS BATTERY OPTION (SCENARIO 1)[a]

S/NO	Description	Amount (₦)	Notes
1	**Capital Expense (CAPEX):** 2.5kVA/2000Watts Solar Power System with two (2) Luminous batteries (200Ah SMF/220Ah Tubular), accessories (60 AMPS MPPT SCC) and installation cost	₦990,000	Rural PHCs are unable to bear the initial burden of the CAPEX. The estimated energy load of a rural PHC is shown in Table 2. 6 units of 320 Watts Panels and Inverter Rating of 24V/2.5kVA.
2	**Operating Expense (OPEX-1)**: Cost of maintaining solar energy system, inverter, cleaning of PV panels, as well as regular maintenance and replacement of two (2) Luminous batteries.	₦381,392.8	Initial intervention is assumed to include a maintenance contract between PHC and the energy developer - with OPEX of ₦85,020 annually. When discounted for an initial 6 years at 9%. It yields payment of ₦381,392.8 resulting in ₦5,297.12 monthly instalments - prior to replacement of the batteries and renewable thereafter
3	**Operating Expense (OPEX-2)**: A series of fixed payments for replacing two (2) Luminous batteries at ₦4,167 monthly for six years	₦300,000	The two luminous batteries have to be replaced by the seventh year. The future value of replacing the batteries is ₦300,000. Assuming ₦50,000 is to be made annually – with a 9% discounting rate -it yields a monthly obligation (investment) of ₦3,115.22 for the first six years of the plant life.
	Approximate Total	**₦1,671,392.8**	**CAPEX: ₦990,000** **TOTAL OPEX: ₦8,412.34 monthly** (for the first six years)

[a]$1 = ₦ 411 (Nigerian Naira) as of 31 August 2021.

₦2.64 million. Table 4 shows the bill of quantities for this scenario with relevant units and costs: 2.5kWp solar energy solution with 4.8kWh lithium-ion storage.

From the financial analysis, the lithium battery solar power system (unlike the Luminous battery scenario) does not entail a maintenance cost mainly because the lithium batteries are sealed. Therefore, a plan is conceived for urban PHCs to repay

Table 4
BILL OF QUANTITIES AND COST ESTIMATES OF LITHIUM BATTERY OPTION (SCENARIO 2)[a]

S/No.	Description	Quantity	Unit Price	Total Price
1	Jinko Solar 370Wp Solar Panels	7	₦90,000.00	₦630,000.00
2	Solar Roof Mounting Kit and Accessories	1	₦0.00	₦0.00
3	Phocos Any Grid Hybrid Inverter Charger	1	₦595,000.00	₦595,000.00
4	Solar PV Disconnect (450VDC, 20A)	1	₦35,000.00	₦35,000.00
5	Shoto SDA10-48100 Lithium-ion Battery	1	₦1,000,000.00	₦1,000,000.00
6	9U Battery Rack	1	₦80,500.00	₦80,500.00
7	DC Battery Disconnect (250A)	1	₦80,000.00	₦80,000.00
8	DC Cables and Battery Lugs	1	₦55,200.00	₦55,200.00
9	AC Cables and Breakers and Panels	Lot	₦95,000.00	₦95,000.00
10	AC and DC Surge Arrestors	Lot	₦69,300.00	₦69,300.00
			TOTAL CAPEX	**₦2,640,000.00**
			OPEX	₦00

[a]$1 = ₦ 411 (Nigerian Naira) as of 31 August 2021.

the initial investment of ₦2.64 million for the solar power system at an estimated 9% annual interest rate (APR). The analysis indicates it will take up to 15 years to complete the repayment. The monthly repayment of the CAPEX (loan) is computed using Equation 1 (derived from the PMT function in Microsoft Excel).

$$\text{Monthly CAPEX Repayment by PHC} = \frac{CAPEX(Monthly\ Interest)}{\left[1+\ (1+Monthly\ Interest)^{-N}\right]} \qquad (1)$$

where:
- Repayment years for the solar power system in Scenario 2 = 15 years
- Monthly Interest $= \frac{Annual\ Interest}{12} = \frac{9\%}{12} = 0.75\%$

(Note: 9% is used here because it is the interest rate on Government Treasury Bills in Nigeria)
- N = Number of monthly repayments for of Solar Power System = 12 * 15 = 180

Applying Equation 1 yields:

$$\text{Monthly CAPEX Repayment by PHC} = \frac{2,640,000\ (0.75\%)}{[1+\ (1.0075)^{-180}]} = \text{₦}26,777$$

The results and foregoing discussion note in Table 5 indicate the following risk allocations:

(i) the initial CAPEX will be borne by a financial institution(s) through a loan(s) provided to the energy developer with the full guarantee and support of the state/federal government (Ministry of Power or the National Primary Health Care Development Agency (NPHCDA))
(ii) the initial CAPEX will be fully sponsored by development partners, international donors as aid and as an intervention project (perhaps with counterpart funding or guarantee from the federal or state government)
(iii) the initial CAPEX is to be repaid by each urban PHC using internally generated revenues and subventions received from the government – NPHCDA. Eventually, each PHC will own the solar energy system (asset) and ensure it is sustainably used, possibly through the provision of energy services, if/when the load profile allows.

Governance Analysis: Organizational Sustainability: RE interventions in healthcare facilities may encounter problems in steering the projects and agents towards the social, economic, and development objectives of providing energy

Table 5
ASSUMPTIONS OF LITHIUM BATTERY (SCENARIO 2) WITH COMPUTED RESULTS AND NOTES

S/NO.	Description	Amount (₦)	Discussion Notes
1	2.5KVA solar power system with two (2) Lithium batteries (excluding installation costs)	₦2,640,000	PHCs lack the capacity to bear the weight of this capital expense (CAPEX), therefore energy developers could receive government loans (at 9% interest) to undertake the project
2	Monthly repayment of the CAPEX (Loan) for future ownership of solar power system by PHCs	₦26,777	Compared to the average monthly energy expenses of urban PHCs (between ₦28,000 and ₦32,500), the potential savings in energy cost is between ₦1,223 and ₦5,723 monthly.

solutions for health access. Concerns typically include designing the best strategy for ensuring the constant payment flux for the operation and maintenance costs in the long run. In addition, the economic viability of the partners' private companies is also a matter of concern. Over time, there are often uncertainties about specific medical needs, the quality of medical services, and expansion of medical equipment and energy load profiles. Previous studies have identified valuable practices for the operating governance of the business models of RE for healthcare facilities in deprived communities, serving as reference points for the structural organization of stakeholders' management and decision-making.

First, efforts should be made to promote collaboration between the energy and health sectors and avoid siloed approaches.[29] Energy institutions comprised of ministries, commissions, and agencies have a key role in the fundraising, planning, design, and implementation of the solar infrastructure. However, the participation of healthcare providers cannot be disregarded since they hold critical information about the technical requirements of the healthcare facilities. In some cases, the current energy demand of healthcare facilities is based on insufficient and obsolete equipment that will require adjustments for future projections. It is up to the healthcare providers to understand and decide upon medical improvements and increments that may impact the design of energy systems and their future demand increases.[30]

Collaborations between the energy and health sectors are essential during the early stages of the project, when collecting data for healthcare access mapping as they tend to define the number of hospital and clinics with or without power supply, including their size, source of power, and functional status.[31] The coordination of such collaborations can be informal or involve official procedures such as periodic mutual inquiries or the exchange of reports.

Moreover, as identified in the previous section, the public, philanthropic, or private sector actors might operate as an external source of financial support for the costs of healthcare facilities in the long term. The participation of the private sector in improving the healthcare facilities' access to energy is essential since it can provide financial solutions that link energy and health needs, alongside technology and innovation capacity.[32]

It is debatable whether private agents would easily steer towards the objective of social justice and equal distribution through electrification. It seems impractical to expect that such agents will accept all the financial burden to electrify understaffed and un-funded healthcare facilities for decades ahead. In contrast to public and philanthropic initiatives, the involvement of the private sector implies that they perceive such energy for health initiatives as business opportunities.[33] Exploring service-based approaches in the case of remote or rural electrification for social objectives can be challenging for players in the private sector because of the lack of infrastructure and the low energy demand.[34] Additionally, there are relevant uncertainties about who the customer is, the consumer ability to pay, the knowledge of risks, and which party should take the known and unknown risks.

In the case of local actors, such as the university teaching hospitals and small and medium-sized businesses supporting the long-term costs of the PHCs, it can be argued that they have better sources of subvention or revenue than the PHCs. Also, PHCs have a small stature in terms of operation and are built in communities that can eventually buy their excess power. Local partners may even contribute to community development. As health improvements prevent illnesses and premature deaths, community development will strengthen these marginalized areas' economic and social fabric.[35] The local university teaching hospitals and businesses can indirectly benefit from a healthier local population that can reach their full potential at work, school, and in civil society.[36]

The risks of the payment performance of the local actors with respect to operation and maintenance costs can be mitigated by reserve funds to ensure future payments in case of delays or defaults.[37] Although it can facilitate the system's sustainability, the lower level of income of the local actors can be a challenge when ensuring the payment performance for the actual operation and maintenance costs and the reserve funds.

Discussion

Law and Policy Incentives for RE: The electricity sector in Nigeria can record significant improvements from a commercial and operational standpoint if the regulatory framework is effective. Specifically, regulations can be reformed or amended to promote greater adoption of RE, through increased coordination between government and regulatory agencies. The focus should be to ensure cost of electricity and financial capacity mismatch is covered by policy incentives that suit existing realities, lower the investors' risks and promote competition.

The implementation of a robust funding framework intended to attract specialized banks and financial institutions should be further encouraged to increase funding for RE projects and for providing financing opportunities at lower interest rates. These institutions include the Bank of Industry, the Central Bank of Nigeria, the Infrastructure Bank of Nigeria, and the Nigerian Sovereign Investment Wealth Fund. The efficacy of the intervention of these financial institutions can be expanded by amending their statutory powers to promote increased funding for RE projects for healthcare purposes.[38] Moreover, while increasing synergy and coordination between government agencies, these agencies may consider interventions in the form of energy subsidies for low-income earners and providers of services that qualify as a public asset, such as healthcare.[39]

The appropriate legal arrangement to promote RE funding ought to align with recognized corporate structures provided under the Companies and Allied Matters

Act (CAMA) 2020. The recognized corporate structures provided under the CAMA include private limited liability companies, public companies, partnerships, limited liability partnerships, and incorporated trustees/non-governmental organizations (NGO). For instance, incorporated trustees and NGOs could be set up with memberships from the government and the private sector with oversight of RE projects. Board appointments of such entities will need to be transparent and operate in accordance with best practices.

Alternatively, the government could employ an existing statutory body already responsible for promoting RE by expanding the scope of its operations. To demonstrate transparency and accountability, appointments to the Board of such a body could be done in such a way to promote adequate representation of the government, private sector, and community groups will have representation. However, the challenge with this sort of arrangement is finding the best way to guarantee effective representation of the different interests, especially those of local groups, within the Board.

Bankable Options: The three factors underlying the financial riskiness of solar energy systems for powering PHCs are:

(a) the scope of the investment,
(b) the burden of cost (CAPEX and OPEX), and
(c) the uncertainty of recouping the investment due to the low revenue/subvention profile of PHCs.

The risk level in regard to the scope of the investment depends on each PHC's electricity load profile and size and location (rural or urban) that determine the feasibility of an energy ecosystem. The allocation of risks and responsibilities should be considered with the objective of sustainably using solar energy to reduce the energy expenses of PHCs and reduce emissions from fossil fuel-fired generator plants. Available data on monthly subventions and energy costs of PHCs provides evidence that Scenario 1 is suitable for rural PHCs, while Scenario 2 would serve the urban PHCs.

From the analysis, regarding the CAPEX and OPEX of both scenarios, the following bankable models could be considered:

(i) Significant tax concessions may be useful and attractive to energy developers, but most of the local players in the solar energy industry lack the capacity to bear the CAPEX burden for powering PHCs, especially in rural areas.
(ii) There is a clear need to prioritize and categorize the powering of PHCs as unique projects[40] like the rural electrification projects being undertaken by the REA. Therefore, the Power Consumer Assistance fund under part VIII of the Electric Power Sector Reform Act of 2005 (EPSR) could be used to subsidize energy investments in PHCs that serve underprivileged power

consumers in rural/low-income communities as stipulated in S.83 (1 and 4). Arguably, PHCs (especially in most rural areas) are underprivileged power consumers and are therefore justifiable candidates for the power consumer assistance fund.

(iii) In addition to providing loans (as in Scenario 2), there could be a business case for commercial banks to expand their service outlets or install automated teller machines closer to PHCs, in effect creating an energy ecosystem of PHCs and commercial banks for which Nigeria's renewable energy tax credit could be used to recoup part of the investment. However, identifying other productive users to join the energy ecosystems could be difficult when the PHCs are sited in rural communities with non-productive energy users.

Organizational Sustainability: Within the Nigerian context, the REA is strategically positioned to handle the coordination between the energy and health sector. It is part of the REA's mission to promote decentralized solutions to increase access to electricity in Nigeria's rural communities, which can be accomplished through social objectives. Over the last five years implementing the NEP, the REA has gained relevant experience deploying solar panels and mini-grid systems for healthcare centers. This includes ongoing projects such as *COVID-19 and Beyond* in partnership with the World Bank, which provides power for equipment used in testing and treating COVID-19-related cases in isolation and treatment centers, as well as PHCs (see item 1 above).

In implementing its projects, the REA creates opportunities for knowledge exchange activities involving health and energy agents, which improves understanding among the project partners. For instance, the REA is in charge of the identification and selection of qualified private developers and project stakeholder engagement.[41] This means the REA often deals with the expectations of government, donors, investors, and communities[42] in activities carried out by highly specialized personnel, sensitive to the community's development needs. While conducting pre-feasibility assessments, the REA has played an active role in compiling evidence-based data from health facilities that are operative and functional in order to select those suitable for solar infrastructure investment. Such tasks have entailed the coordination of energy and health institutions, allowing the exchange of information among the inter-sectoral institutions.

As REA leadership seems inevitable, it might be the case to formalize its function in the electrification of healthcare facilities. For instance, such outcomes may be achieved through growing its competencies in relevant areas and developing a specific decision-making body in charge of the tasks. Perhaps a healthcare electrification unit could be created to collaborate with NPHCDA in managing the prepayment of the OPEX. This entity could also monitor the project members' responsibilities over the years and act to enforce the allocated risk mechanisms, such as taking legal steps or penalizing infringements.

Conclusions and Policy Implications

A just energy access system may save lives. The COVID-19 crisis has had a crucial role in emphasizing this factor.[43] However, short-term responses to emergencies such as COVID-19 cannot replace long-term strategic planning. Decentralized solar power holds great potential to promote resilient health systems in African countries like Nigeria, provided the enabling factors are in place, such as policy direction, strategic planning, and efforts from the health and energy sectors, regulatory authorities, and investors.

The envisioned challenges of solar power for fragile and resource-constrained PHCs in Nigeria need an innovative business model in which sustainability for the entire lifespan of the project must play a key role. Typically, external financial and human resource opportunities must ensure the energy systems work long-term. Otherwise, if proper maintenance and repair services are not provided, the solar infrastructures will risk becoming inoperative “stranded assets.”

For energy developers, the profitability of the above propositions can be better appreciated when viewed through the lens of economic scales, with about 30,000 PHCs to be powered. Therefore, powering several PHCs within a state or local government area could make more business sense, but it would be useful to undertake empirical analyses of such a scenario. Even though a quantitative analysis regarding the energy ecosystem surrounding PHCs is possible, the relevant data is lacking. It is therefore expedient to ensure that energy audits for all PHCs are undertaken to justify the deployment of any off-grid energy solutions. The outcome could highlight the opportunities that exist for renewable energy developers.

Effective measures to secure off-grid energy infrastructure should be put in place as most of the PHCs are in remote locations and equipment theft could pose a challenge. This analysis has excluded the additional cost of providing security. Admittedly, this could also create a potential niche market for insurance companies who may want to mitigate the risk for prospective solar energy investors in the healthcare sector.

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