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Electrifying Africa

Contents

Oxford Energy Forum 114 looked at liberalization and decarbonization of electricity systems around the world, especially outside the OECD (Organisation for Economic Co-operation and Development). Previously, Forum 104 had studied the challenges facing the electricity sector in OECD countries, with a focus on Europe. Regardless of their circumstances, virtually all countries are undergoing a fundamental transformation of the sector, involving a significant increase in the role of renewable energy, greater decentralization of energy resources, and the adoption of new ‘smart’ digital technologies. This transformation creates opportunities for expanded consumer access and participation, as well as for decarbonization of energy. However, it also requires new policies, markets, and regulations, as well as new approaches to investment, operations, industry structure, and business models.

This issue of the Forum focuses on the electrification of Africa, especially sub-Saharan Africa (SSA). Due to significant expected population growth, the number of Africans without electricity access in 2030 may not fall much from today’s level of about 600 million, which is about 60 per cent of the world’s current population without access to electricity. The articles cover a wide variety of countries and issues, focusing on barriers to meeting electrification objectives and ways to overcome them. Here are some of the general themes.

- *The rationale for electrification.* Electrification is expected to contribute to meeting many of the UN's Sustainable Development Goals by 2030, including ending poverty, ensuring quality education, and ensuring access to energy, while promoting economic growth, gender equality and other goals. However, many authors introduce important qualifications. *Gregor Schwerhoff* argues that electrification could undermine other development goals, including access to clean energy and climate action, if it is carbon-intensive. *Catherine Wolfram and colleagues* argue that electrification may not be as important as other policy issues (such as health) and may not contribute much to achieving the Sustainable Development Goals. *Roxanne Rahnama and Ignacio Pérez Arriaga* maintain that effective electrification requires an understanding of ability to pay, the value of unserved energy, and how consumers value different attributes of electricity service. *Maryse Labriet* stresses that energy access must be measured in quantitative and qualitative terms, and to be meaningful must be accompanied by clean cooking facilities. *Anna Aevarsdottir and colleagues* emphasize the need for new financing mechanisms to make electrification a reality.

- *The generation mix.* Coal is currently an important part of the SSA generation mix and investment in new coal-fired plants continues. The authors recognize that renewable power will play an increasingly important role in African electricity, whether at large scale or in isolated systems. There is potential to 'leapfrog' carbon-intensive generation, especially in isolated rural areas. *Anna Aevarsdottir and colleagues* argue that even low levels of renewable electrification, especially solar lamps, can bring substantial economic and noneconomic benefits. Other authors, including *Lapo Pistelli* as well as *Rahmatallah Poudineh and Tade Oyewunmi,* emphasize the potential for natural gas to play a key role in meeting Africa's energy needs.

- *The role of China.* China plays an important and controversial role in the electrification of Africa. *Emma Gordon* credits the good Ethiopian track record in completing infrastructure projects in part to the government's partnership with China. *Laurence Harris* notes that, for SSA, China is the largest national source of investment in the electricity sector's expansion and upgrading. *Simone Tagliapietra* points out that Africa is part of China's 'One Belt, One Road' initiative and that China has focused on coal and large hydropower projects. He says that China seems not to consider the environmental and social issues that prevent most international financing institutions from supporting coal.

- *Decentralized and centralized systems.* A number of authors, including *Laurence Harris* and *Carlo Papa and Giuseppe Montesano*, argue that both the declining cost of renewable power and the adoption of smart technologies support the development of decentralized rural electricity systems and their connection to central grids. *Anteneh Dagnachew and colleagues* maintain that on-grid electricity would be cost-effective in most cases, but renewable mini-grid technologies could provide electricity access to over 180 million people by 2030. *Emma Gordon* explains that the Ethiopian government has traditionally encouraged large-scale projects connected to the central grid, while the Kenyan government has promoted innovation by private operators in decentralized systems. However, even in those two countries, integrating centralized and decentralized systems is becoming important.

- *Consumer preferences and local participation in rural electrification*. Most of SSA's unconnected consumers are in rural areas. *Roxanne Rahnama and Ignacio Pérez Arriaga* argue that successful electrification of rural populations requires consumer-centric planning and business models. *Maryse Labriet* agrees and emphasizes the importance of a strong enabling environment, a solid supply of products and services, and a robust demand for these products and services. *Anna Aevarsdottir and colleagues* emphasize the limits to electrification and the need for new financing mechanisms.

- *The role of institutions, policies, and regulatory frameworks*. *Emma Gordon* explains how politics influences the process of electrification, contrasting the political support in Kenya for private enterprise with the Ethiopian preference for government control. She also notes the political risks in Kenya related to corruption, ethnic conflict, and political instability. *Neil McCulloch and colleagues* stress the importance of taking local political context into account when deciding on aid policy. *Rahmatallah Poudineh and Tade Oyewunmi* illustrate the need to improve legal and institutional frameworks, introduce independent regulation, and liberalize the electricity sector in order to support investment and improve operating efficiency.

- *New financial architectures*. Many of the articles propose ways to finance the enormous investment requirements, with de-risking of private investment being a common theme. *Laurence Harris* proposes a financing systems framework that looks at the entire process from financial source to implementation. *Lapo Pistelli* identifies various credit guarantee proposals. *Rahmatallah Poudineh and Tade Oyewunmi* recommend improvements for institutions, policies, and regulation. *Carlo Papa and Giuseppe Montesano* suggest creating separate asset classes and clusters of investment to attract private investors with different time frames and risk–return profiles. *Simone Tagliapietra* argues that SSA governments must reform their power sectors to facilitate international private investment and that international public finance should be better coordinated and designed to promote private investment.

- *Climate change. Simone Tagliapietra* concludes by reminding readers that low-carbon electrification of Africa's growing population is critical in the global fight against climate change. *Anteneh Dagnachew and colleagues* argue that the cost of electrifying Africa would be lower if climate change policies were adopted worldwide; the savings would result from improved efficiency in the use of energy. *Gregor Schwerhoff* says that, although investment in new coal plants continues, the case for coal is weakening, in particular due to the risk of stranded assets.

This Forum has been organized into four parts. The first offers an overall perspective on the challenges of electrifying Africa and identifies proposals for addressing them. The second looks at system-wide issues related to expanding output and supply security, including the potential for large-scale generation projects and the integration of national and local grids. The third focuses on rural electrification, especially from the perspective of consumers. The final part explores perhaps the most difficult challenge, namely how to finance the enormous investment requirements to achieve universal electricity access in Africa.

An overview of the electrification of Africa

Laurence Harris identifies three tasks for electrifying Africa, in particular SSA. The first is to expand the output and reliability of existing centralized power systems that supply connected consumers. The second is to connect the unconnected population, which is mainly rural, in decentralized systems and mini-grids that, using developments in hardware and digital control systems, can at a later stage link to wide-area (centralized) grids. The third is to decarbonize the energy mix, in particular reducing the importance of coal, high-carbon local biomass, and diesel (which at present is widely used as an energy source in stand-alone generators). The author argues that this transformation requires advancements in engineering and investment. For engineering, the key is to exploit the already achieved and continuing cost reductions of renewables as well as recent advances in system design and smart grids to connect generation, storage, and demand from national and local systems. For finance, since investment is well below the rate required to achieve universal electricity access by 2030, the author proposes a financing systems framework that involves a many-stepped process from financial source to implementation of real investment. He illustrates how the framework applies to investment in centralized systems (where new financial instruments and institutions can increase investor return–risk ratios), and how it differs for investment in decentralized clean electricity systems.

Increasing the output and reliability of integrated systems

Lapo Pistelli argues that the African continent has huge renewable energy potential and abundant natural gas that together can deliver stable and environmentally sustainable electricity generation. The author refers to the untapped potential of natural gas and cites evidence that new (fossil-fuel-fired) power projects in Africa burn coal and even diesel, not natural gas. After reviewing reasons for the lack of investment in gas-fired plants, the author identifies models for supporting that investment. One, from Ghana, involves World Bank guarantees and other payment securities (subject to policy reforms that ensure the power sector is able to sustain itself) that helped attract additional sources of finance. The European Fund for Sustainable Development Guarantee is another form of credit enhancement guarantee, but natural-gas-fired plants are not currently a primary target for the fund. A third is the Scaling Solar programme, designed by the World Bank to create viable markets for grid-connected solar projects. More generally, the author argues that the key to electrifying Africa is developing new forms of cooperation to de-risk investment.

Rahmatallah Poudineh and Tade Oyewunmi argue that domestic gas-to-power projects can contribute significantly to universal energy access as well as to the security and sustainability of energy supply in Tanzania and Nigeria, but these countries need to overcome a range of challenges to enable this. For Nigeria, the main challenges are ensuring the effectiveness of legal and institutional reforms, establishing an independent regulator for domestic gas supply, investing in infrastructure, transitioning to a more liberalized and market-led pricing and resource allocation model, boosting the stability of the power transmission network, and mitigating the liquidity crisis in the power sector. For Tanzania, the challenges are investing in generation capacity, developing gas reserves upstream, leveraging the technical and operational expertise of international oil companies for offshore reserves, addressing the liquidity crisis faced by the state-owned utility, TANESCO, and reducing energy losses in the network.

Carlo Papa and Giuseppe Montesano propose three enablers for African electrification in conditions of rapid population growth and urbanization. First, from a technical perspective, utility-scale projects could electrify populations living in or near towns; standardized, decentralized mini-grids could be temporary solutions for remote rural areas and could eventually connect to the national grids. Second, the proposed business model would decouple generation from the mini-grid system, restricting the latter to distribution and supply to end-users, while sourcing power from bigger renewable power plants built nearby and serving more than one mini-grid. Third, on finance, the authors suggest creating separate asset classes and clusters of investment – from mini-grids to industrial-scale projects and high-voltage grids – that could attract private investors with different time frames and risk–return profiles. The authors emphasize the importance of reaching a consensus with affected communities, close cooperation with governments and international institutions, and ensuring a clear policy framework with a robust regulatory environment.

Anteneh Dagnachew and colleagues use scenario modelling to analyse the costs of providing universal access to electricity in SSA. Against a business-as-usual scenario, the authors compare two scenarios: one achieves universal access without climate policy, and the other achieves it with global climate mitigation policy imposed everywhere. They draw three conclusions. First, new policies and initiatives are needed to ensure access to electricity for over 500 million people, on top of the business-as-usual effort. On-grid electricity would be cost-effective in most cases, but renewable mini-grid technologies could provide electricity access to over 180 million people. Second, universal electricity access requires annual investment of US$27 billion assuming a global climate policy and US$33 billion assuming no global climate policy; the 'savings' in the cost of achieving full access result from greater efficiency, but the calculation does not include the cost of introducing climate policy. Third, institutions need to stimulate innovation in supply technology and business models by providing the necessary incentives for innovation by establishing functioning electricity markets.

Gregor Schwerhoff points out that, of total electricity generation in Africa in 2015, only 0.33 per cent was sourced from solar power and 0.96 per cent from wind power, while coal and gas dominated electricity generation. The author refers to recent research which indicates that wind and solar power will become the dominant source of electricity on the continent by mid-century if at least minimal importance is given to health benefits and climate change mitigation. This development is being driven by falling prices for renewables and the excellent potential for renewables in Africa. Such a shift in the energy strategy would have important repercussions for the way electrification is planned. Since the size of renewable power plants can be adjusted to needs, decentralized electricity grids may be more attractive than connections to the distant national grid in many cases. Furthermore, national grids will have to be built to accommodate long-range exchange of electricity from variable sources. In spite of the advantages of renewable energy, the author points to the significant investment in new coal-fired generation, and to the continued bias, notably from financial institutions, in favour of conventional power plants. However, he notes that the case for coal power is weakening, in particular due to the risk of stranded assets.

Decentralized clean electrification: a consumer perspective

Roxanne Rahnama and Ignacio Pérez-Arriaga argue that electrification planning is too often addressed exclusively from techno-economic perspectives, without seriously questioning the ways in which electricity services are perceived, used, and paid for by consumers. They argue that the complexity of electricity consumers has often been neglected in the discourse on financially sustainable electrification, especially for the rural poor. To serve these populations well requires an understanding of ability to pay, willingness to pay, the value of unserved energy, and how consumers value different attributes of electricity service. In short, successful electrification requires consumer-centred policies and business models.

Maryse Labriet draws on the case of Mali to support three main points. First, the definition of electricity access must include the qualitative and quantitative dimensions of access. Second, planning should focus not on electricity but on the energy services provided. This requires a shift from top-down to bottom-up planning of the electricity system. Third, governance should involve stakeholders from multiple sectors, not just energy, as well as local authorities. The author emphasizes that an integrated framework for electricity access relies on a strong enabling environment, a solid supply of products and services, and a robust demand for these products and services. Finally, she stresses that energy access requires electricity as well as facilities for clean cooking.

Anna Aevarsdottir and colleagues discuss the potential and limitations of off-grid solar. The authors argue that due to high irradiation potential, the falling cost of solar photovoltaic, the speed of roll-out, and the limited capital investment required (compared to grid connections), solar home systems may be attractive solutions in sparsely populated rural areas of SSA. Even low levels of electrification, especially solar lamps, can bring substantial economic and noneconomic benefits. The authors cite a study in Tanzania that showed that the benefits of solar lamps include lower payments for lighting, kerosene, and mobile phone charging, along with increased income and even happiness. However, limited willingness and ability to pay will need to be addressed through broader financing mechanisms, flexible payment schemes, and possibly short-term targeted subsidies. Furthermore, available off-grid solutions are unlikely to provide the electricity needed for larger-scale productive uses; these activities will require mini-grid or on-grid solutions.

Catherine Wolfram and colleagues challenge what they consider to be a commonly held belief that access to reliable electricity drives development and is essential for job creation, women's empowerment, and combating poverty. Drawing on an experiment in Kenya that compared two sample groups (a 'treatment" group given access to electricity and a 'control' group not given access), the authors find no difference between the two groups after 18 months and again after 32 months. For instance, children's test scores remained the same in the two groups. Although the authors recognize the risk of generalizing the results, they explain why one should be cautious in assuming that electrification is the key to rapid economic growth: access to electricity does not make poor people rich; other interventions (e.g. to improve health) may deserve a higher priority; electricity is more useful if you can afford to buy appliances; and poor reliability makes electricity less valuable.

Finance, investment and politics

Emma Gordon compares Ethiopia and Kenya to show how government policy and country risk affect renewable energy investment. Both countries aim to encourage foreign investment in renewable energy, with Ethiopia looking most favourably on large utility-scale projects and Kenya offering better opportunities for off-grid projects. Although Ethiopia has a comparatively low country risk and low levels of corruption, the government closely controls the sector, and the regulatory framework for private investment is incomplete, leaving investors very reliant on government support. In contrast, Kenya has a long history of private investment and of innovative off-grid solutions, with a well-developed regulatory framework. However, investors in Kenya face political risks, especially due to corruption, the high levels of ethnic competition, and the potential for protracted litigation and violent protests that can delay or stop investment projects.

Niel McCulloch and colleagues examines how aid donors have tried to take political context into account in supporting power sector reform in sub-Saharan Africa. The author argues that aid programme designs should start with a detailed analysis of the underlying motivations of the key actors and institutions to identify reform pathways that are politically feasible, rather than just those that are technically desirable. Development partners need to balance activities that are consistent with the current political equilibrium with those supporting legitimate domestic actors that challenge the status quo. Researchers need to test whether programmes that adopt more politically savvy approaches are more effective and how their success or failure is affected by the nature of the political context and the way in which they are implemented.

Simone Tagliapietra argues that two changes are needed in order to scale up the investment required to make (clean) power available to all in Africa. First, SSA countries must reform their power sectors to facilitate international private investment. Reforms must make utilities financially sustainable, while ending the subsidization of inefficient utilities and old forms of energy, like kerosene. Second, international public finance should be better coordinated and designed to promote private investment, both for large-scale, low-carbon projects and for distributed rural electrification projects. Coordination could be improved by streamlining different financial initiatives, notably those led by the European Union. To support private investment, these international financial institutions should encourage domestic power sector reforms and devise innovative financial products, especially to overcome the barriers to investment in small-grid and off-grid rural electricity systems. The author ends by reminding readers that low-carbon electrification of Africa's growing population is critical in the fight against climate change.

Readers may also be interested to read an article in Forum 114 on South Africa, which country is something of an outlier in sub-Saharan Africa, accounting for fully half of the generation there and having achieved much higher levels of access to power than elsewhere in the region.

FINANCING SYSTEM CHALLENGES FOR ENERGY TRANSFORMATION IN AFRICA

Laurence Harris

The production, distribution, and consumption of electricity in Africa is a disaster that blights the continent's economic and social prospects. And it has the potential to become much worse. The twentieth century powersystems at the heart of the present supply infrastructure are inadequate to meet present day demand for reliable power. For the future the projected growth of both population and GDP per capita in Africa implies expanding demand resulting in worsening shortfalls unless radical strategies of expansion and change are implemented.

Engineering advances for three strategic tasks

Strategies for 'electrifying Africa' have to address three great tasks:

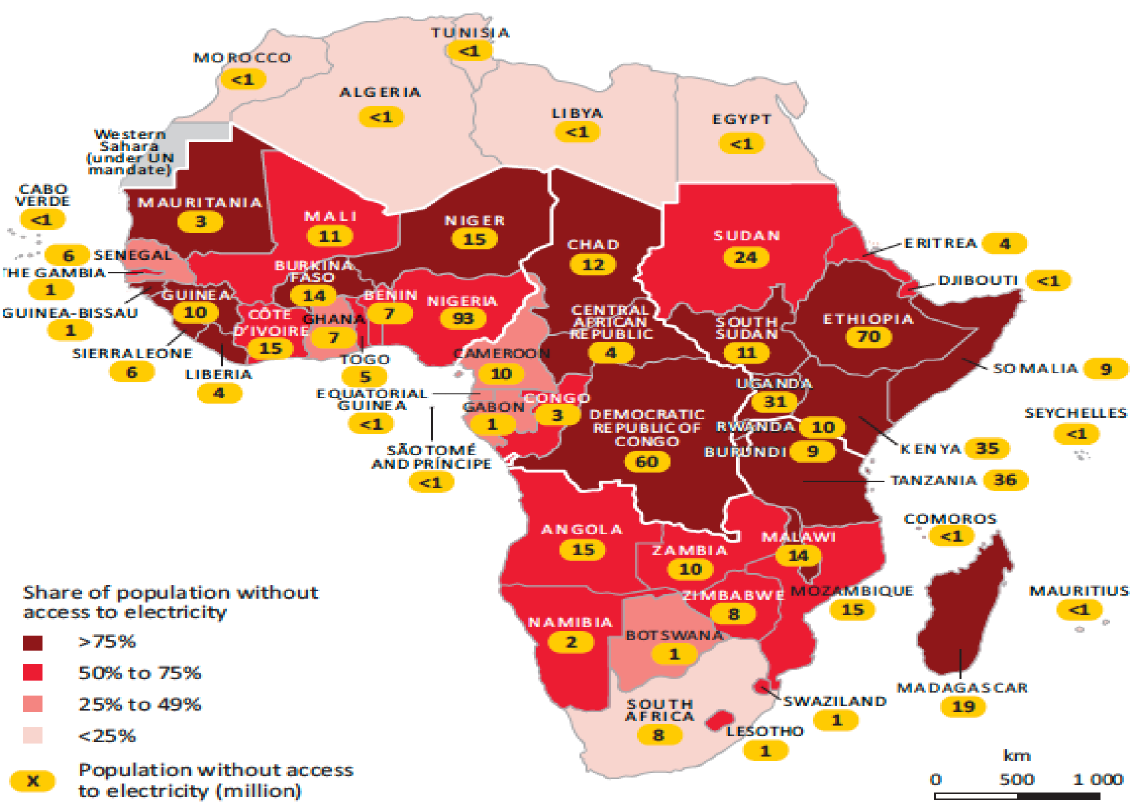
Task 1. Expanding both the output and reliability of existing power systems.

These **centralised** systems for power generation, transmission and distribution, inherited from the twentieth century, involve large scale generation and transmission through centralized grids. Investing in their expansion is fundamental to Africa's electrification. But investment has to encompass major, challenging change of two types. New and upgraded capacity incorporating new generating and transmission technology is required; and the institutional and market structures that characterized the systems historically – utilities as state owned, vertically integrated, monopolies in poorly regulated and subsidized markets – are not generally sustainable without major change.

The capacity of sub-Saharan Africa's centralised systems was far below those of other regions of the global south in 1980 and has not matched population growth since then, falling further behind those of the other regions.

Investing in the centralised systems principally addresses the currently unsatisfied and future growth of demand for reliable power from existing, connected consumers. Capacity and grid expansion can also increase the numbers connected but cannot quickly provide coverage for large numbers in unconnected rural areas far from established grids.

Share of population without access



Source: International Energy Agency. Africa Energy Outlook, 2014, Figure 1.6

Task 2. Increasing access to electricity by connecting the unconnected.

More than 50 per cent of sub-Saharan Africa's population has no access to power from the centralised system (see figure on page 6).

Partly because lack of access is particularly acute for rural populations spread over large distances, in some countries investment in grid expansion is not a cost-effective means to reduce it substantially and rapidly. Even South Africa, which inherited an extensive, large capacity centralised system in 1994 and embarked on a successful programme of extending grid connections to provide access for the unconnected, found by 1999 that grid extension could not efficiently and quickly connect more than 80 per cent of the population. Consequently much recent attention has focused on the development of **decentralized** small systems in which distributed local generation is linked to mini-grids.

The feasibility of decentralized systems has been greatly increased in recent years by recent developments in hardware and digital control systems. Their benefits include their relative cost effectiveness in locations distant from a centralised grid; their flexibility in being able to speedily supply new industrial or residential locations; their short development period and potential for early revenue streams; their scalability through linking both mini-grids and additional local generators; and the possibility of linking distributed generation to the centralised grid.

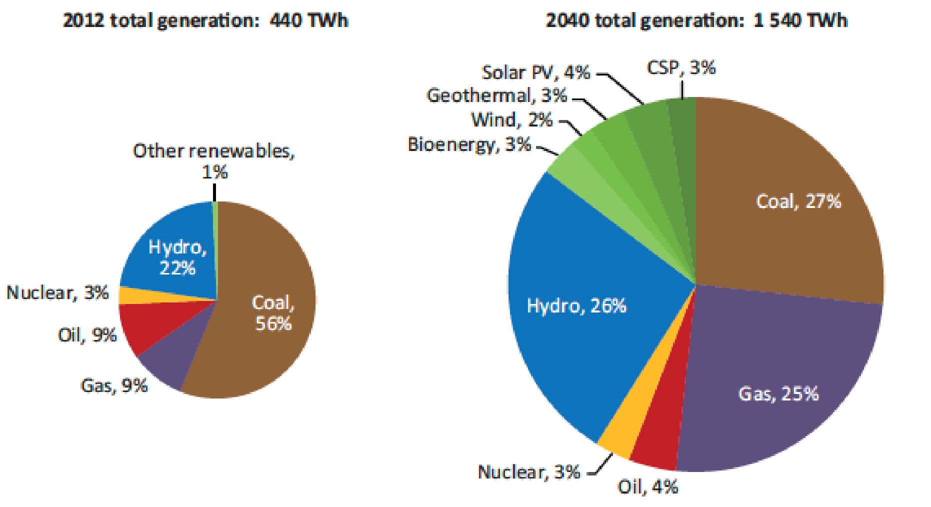
The technological advances that have made decentralised systems feasible and attractive are linked to advances in the use of renewables in generation, for decentralised systems can be seen sourcing energy locally from solar, wind, biomass, and local hydro, while being autonomous from commercial supply chains of fossil fuels (or partly autonomous in the case of hybrid source decentralized systems). Thus they are generally analysed as decentralised clean power systems enabling countries (partially) to develop twenty-first century power by 'leapfrogging' twentieth century centralised fossil fuel based systems. But, since renewable distributed generation can, subject to geography, be linked to existing and extended fixed grids investment in both should be seen as complementary. With a feasible objective of achieving hybrid power over linked grids, decentralised clean systems are sometimes regarded as transitional systems for the decades before previously unconnected regions are connected to hybrid centralised systems.

Task 3. Energy mix

Sub-Saharan Africa, in line with global obligations, has the task of shifting its energy mix further towards a low carbon emissions average. Within COP21's 'ground-up' process of 'intended nationally determined contributions', in the Paris agreement several African countries committed to significant reductions in emissions. For example, compared to business-as-usual levels Angola pledged to reduce emissions unconditionally by 3 per cent by 2030, with an additional 15 per cent reduction conditional upon support, and Nigeria pledged to reduce emissions by 20 per cent unconditionally and 4 per cent conditionally. Investing in Africa's electrification in ways that increase the proportion of clean energy sources is required to support those goals. So is investment in the centralised grid to reduce wasteful energy transmission losses that currently occur in sub-Saharan countries at a rate much higher than the global average through old and poorly maintained grids.

Apart from climate change emission-reducing changes in the region's energy mix is also seen as being in African countries' interests partly because of the cost that climate change imposes on the region; partly because of the negative public health impact of

Electricity generation by fuel in sub-Saharan Africa in the New Economic Policies Scenario, 2012 and 2040



Source: International Energy Agency (2014) African Energy Outlook: World Energy Outlook Special Report Figure 2.6

high emission fuels; and possibly within an energy security strategy insofar as it reduces dependence on international supplies of fossil fuels.

Fossil fuels accounted for 74 per cent of Sub-Saharan Africa's power generation sources in 2012, with coal accounting for 54 per cent and oil 9 per cent (see final figure). The overall figures mask great variations with, at one extreme, South Africa's generation being almost entirely coal based while generation in Central Africa and Mozambique is predominantly from hydro sources.

A leading scenario for a changed energy mix envisages increasing the share of hydro to 26 per cent (from 22 per cent) and other renewables such as solar PV and wind to 15 per cent (from 1 per cent) by 2040 (see figure on page 7). Within it, a move toward cleaner fossil fuels involves a switch from oil and coal towards gas.

To achieve electricity sector transformation in Africa that addresses those three tasks – and the many sub categories of tasks they involve – requires strategic advances in two distinct spheres: engineering and investment. Rapid technological advances, particularly in system design, now offer solutions to most of the engineering challenges for centralised, decentralised and hybrid systems, but investment lags far behind.

Engineering advances have transformed power generation through advances in the design of solar photovoltaic cells and their large scale manufacturing process, by the design of wind turbines and by technologies for efficient use of gas and oil. At the same time, storage technologies have developed fast, especially in the mass production of lithium-ion batteries. Costs depend on the mode in which they are used, ranging from large capacity energy storage systems within utilities to meet peak demands to household battery storage to overcome the variability of supply from solar PV panels. According to a recent estimate median costs of lithium-ion battery storage decreased by between 11 per cent and 12 per cent between 2015 and 2016.

But of equal or greater significance are engineering's technical advances in system design. Generating electricity with PV cells, wind turbines or fossil fuels is relatively simple, but systems that make the output usable and enhance operational efficiency pose complex problems. The output of centralised utilities has to be transmitted and distributed across wide area grids and local connections while the output of local generators has to be distributed to consumers across mini-grids, and ultimately connected to a centralised grid permitting two way flows. 'Smart grids' that integrate generation and storage from a range of (decentralised and central) sources, and manage both demand and supply to minimise fluctuating and costly imbalances, are now feasible. Digital technology enables networks to move electricity from high to low voltage systems and to control feed-ins, and the design of systems that combine different sources, storage, and controls efficiently is now routine. The associated new hardware technology of automated controls that ensure rapid switching between sources, control of supply surges, and supply responsiveness to demand changes is now established. Meanwhile, mobile phone technology, particularly the techniques of mobile money transfer pioneered by M-PESA in Kenya, have led to the development of payment systems designed to suit low income consumers of decentralised clean electricity.

While engineering advances have opened new routes to Africa's electrification recent investment trends have fallen well short of the high rates of real investment that would be required to implement the strategies that they make feasible. Focusing on Task 2 alone, connecting the unconnected, the International Energy Agency (International Energy Agency, 2011. *Energy for all; financing access for the poor*) calculated that the additional investment required between 2010 and 2030 to achieve universal access in sub-Saharan Africa would be USD 389 billion (constant 2010 USD), but the region's total annual investment in power (for both connected users and new connections) is well below the annualized rate required for that scenario.

This article outlines some selected issues in financing the costs of the investment needed for Africa's electrification.

A financing systems framework

'How can investment in Africa's electrification be financed?' is susceptible to simple, broad brush answers. One approach is to calculate the (total or annualized) capital cost of reaching a target level of megawatts per person for sub-Saharan Africa over a certain period and compare it with an estimate of funds that could be available from various sources.

But such calculations do not take us far, for the devil is in the detail. Analyses that grasp key details from a conventional perspective on finance focus on the risk-return implications and risk sharing characteristics of financial instruments; the optimal combination of a variety of debt instruments and equity finance. Similarly, important studies concern the range of combinations of state, concessional foreign, and 'private' finance, their implications for risk-sharing, cost and revenue sharing, and, hence, the cost of capital invested.

This article is founded on a more holistic approach to financing. The approach, a *Financing Systems Framework*, treats finance as a connected set of quantities, prices and choices linked in a many-stepped process from financial source to implementation of real investment. It is a process that occurs within institutional constraints that can either hinder or facilitate it and which demand policy interventions.

Seeing finance for investment in Africa's electrification as a process differs from the static approach of calculating pools of funds available; it enables us to consider key issues at each stage of the process. Those include, fundamentally, the risk-return characteristics of actors' portfolio allocation decisions. They include the institutional constraints affecting the process, stretching all the way from financial market structures, through financial and energy market regulations to African countries' governance, stakeholder interests, and incentive structures, and, further, to the financial literacy and customs, of retail customers as well as their income level and volatility. Thus, the financing systems framework enables us to identify financing problems at key points, from the conditions of global financial markets through the many intermediate stages to the capacity of African countries, communities, and individuals to use finance for electricity investment.

The need for a financing system approach to complement existing studies of specific financing mechanisms is illustrated by simple 'failure' scenarios. Imagine the consequences for sustained investment if new financial instruments are devised that improve the return risk ratio for international investors in African electricity projects but the projects' expected revenue streams fail to materialize because local politics or culture, that had not been taken into account, undermine payment of electricity fees. Illustrative examples are the past experience of South Africa in collecting payments for municipal electricity and, in respect of a different infrastructure category, the South African revolt against fees for use of Sanral's debt-financed upgraded road network. Focusing only upon the design of suitable instruments for channeling wholesale finance to African power projects can be followed by unpleasant financial surprises unless complemented by measures to address institutional issues across the whole financing system.

Since Africa's electrification involves three major tasks, financing systems differ according to the task: investment and finance for modernising and expanding centralised utilities and grids differs from that needed by decentralised power, and some specific financing systems relate to investment for emissions reduction. Instead of a comprehensive analysis of issues at all points of different types of financing systems this paper the following sections focus on some illustrative points. I first discuss some key aspects of financing systems for investment in centralised systems, followed by distinctive financing system aspects applicable to investment in decentralized systems.

Infrastructure financing of centralised systems' real investment: Macroeconomic fundamentals

Financing investment in utility and grid power is broadly similar to financing other large, long-term infrastructure projects. Desirable levels of global investment in infrastructure as a whole would generate a large demand for funds and financing the upgrading of Africa's centralized generation and grid systems has to compete globally against the world's infrastructure projects. One scenario calculation is that the global infrastructure investment required to support currently projected global economic growth would absorb USD 3.3 trillion per annum on average from 2016 through 2030 or a cumulative total of USD 49.1 trillion of which USD 14.7 is allocated to power projects (see here).

Taking that as a starting point for African electrification's financing process it may be argued that the first step is to consider how to attract finance into infrastructure from institutional investors' portfolios. Although infrastructure assets, with their long and stable income steams (post development) are compatible with the liability structure of many institutional investors such as pension funds, the main asset classes for institutional investors as a whole are public equity and other financial market assets. For example, in McKinsey it is argued that institutional investors have some USD 120 trillion under management which governments and other stakeholders can attempt to attract for investment in infrastructure. To the extent that institutional investors switch into infrastructure financing the issue is how to make fund allocations into African electrification at least as attractive in terms of risk and return as infrastructure projects in the countries of developed and other developing regions (when risk and return are judged broadly to include such factors as the cost and risk of institutional obstacles).

Attracting funds from global investment portfolios is at one end of a financing process. I focus on it here to highlight that if studies calculate such financial resources but neglect macroeconomic fundamentals they obscure some basic issues that have to be faced by strategies for African electrification.

Increased investment in expanding and upgrading the infrastructure absorbs real resources that must be matched by real domestic or foreign saving. Without an increase in domestic saving or a reallocation of domestic saving from other investment projects, the real resources come from an increased inflow of foreign saving. In national income accounting terms a large investment programme from 2016 to 2030 implies higher current account deficits on the balance of payments matching the excess of domestic real investment over domestic real saving.

Thus, financing of electrification investment is fundamentally a macroeconomic problem. One financial implication of that macroeconomic constraint, neglected in most writing on electrification strategy, is that funding it from foreign saving through loans or debt adds to the country's foreign liabilities and complicates its debt management. Ultimately the sustainability of the country's debt depends on the macroeconomics of the growth rate and macro policy's management of domestic sectors' saving and investment rates. Attracting foreign saving to match electrification investment requires more than a capital budgeting assessment of each project or programme; assessment of its implications for the country's debt management and the macroeconomic policies it requires should not be neglected.

Macroeconomics also underlines the value of distinguishing between stocks and flows at this stage of the financing process. Calculations of the amount of wealth potentially available in the portfolios of institutional investors refer to an accumulated stock of past saving that, in global accounting, is, in principle, matched by a stock of already existing physical capital. Investment in Africa's electrification is a flow to be calculated over a planning horizon period. In recent years a high proportion of the foreign saving being invested in sub-Saharan Africa's centralised electricity systems originates from China's flow of new resources measured by the country's excess of domestic saving (current account surplus).

For sub-Saharan Africa China is the largest national source of investment in the sector's expansion and upgrading. Financing is tied to Chinese contractors designing and carrying out the projects. It is estimated that between 2010 and 2020 China will have completed 145 sub Saharan Africa projects for new capacity in generation, transmission and distribution (see table). Of these it is estimated that 78 per cent are financed wholly by Chinese entities and another 10 per cent are partially financed by China in tandem with multilateral development banks and other sources.

Financial instruments and institutions

Whatever the ultimate source of savings for investment in African electrification, the financing process may be strengthened by designing financial instruments tailored to increase investors' return- risk ratios. Such innovations imply associated institutional changes to create new markets, new financial intermediation, or new principal-agent relations, as is illustrated by two recent examples.

The proposal of Arezki et. al. (Arezki, R., Bolton, P., Peters, S., Samama, F. and Stiglitz, J., 2017. From global savings glut to financing infrastructure. *Economic Policy*, *32*(90), pp.221-261) for increasing institutional investors' financing of infrastructure such as African centralised electricity systems envisages a transformation of public-private partnerships (public agency and private developer/operator) into fourfold partnerships that additionally have development banks and institutional investors as partners. Although the entities involved are not unusual in project financing this proposal places them on a partnership footing with a new, proactive agency role for development banks as initiators and coordinators. The proposed financing mechanism associated with the institutional change is for development banks to create pools of infrastructure assets that are the basis for asset backed securities sold to investors.

A different innovation in this space is the fledgling market in green bonds that could be a channel for funding clean electricity projects in Africa as well as other climate change mitigation projects. Although the market is very small, annual new bond issues have initially grown at a fast rate, principally due to issues by development banks and corporations (see figure). Chinese

Overview of Chinese power projects in sub-Saharan Africa, 2010-20

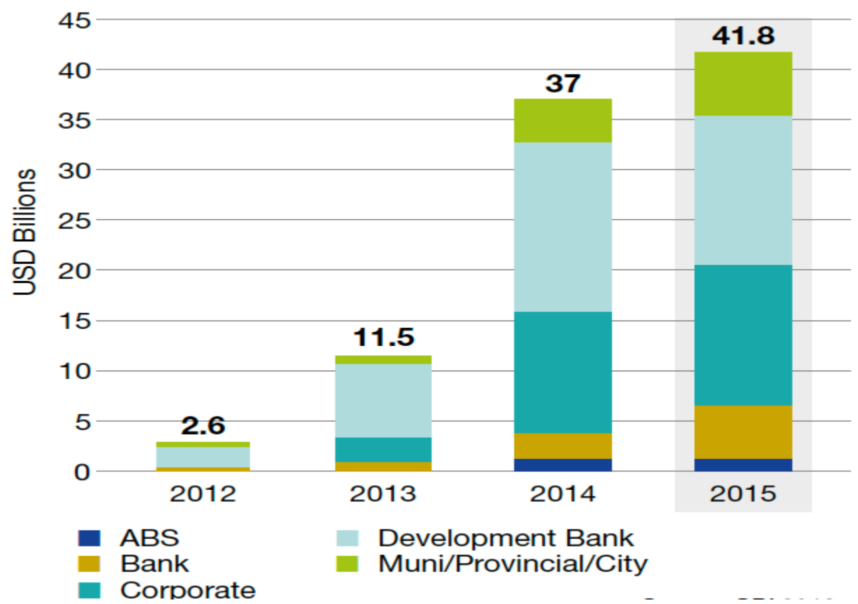
	Generation capacity			T&D capacity		
	Completed projects	Under construction	Planned and financed	Completed projects	Under construction	Planned and financed
East Africa	14	9	5	10	10	1
West Africa	17	4	2	6	2	2
Central Africa	8	5	2	5	1	2
Southern Africa	15	7	8	4	5	1
Total	54	25	17	25	18	6
	96			49		

Source: International Energy Agency, 2016. Boosting the power sector in Sub Saharan Africa, China's Involvement, Table 1 entities, international and regional development banks, and US borrowers have dominated issues, but, with the exception of a small amount of green bonds issued by the African Development Bank, green investment in Africa has not had a significant presence. The potential contribution of green bonds, their attraction as an asset class for institutional investors, is twofold.

Inclusion in institutions' portfolios may increase their attractiveness to a growing class of savers who value environmental benefits, and they act as a hedge against the climate change risks (such as the risk of stranded assets) to which other securities in their portfolio are subject.

Although increasing numbers of institutional investors are announcing strategies for increasing their portfolios' green hue, the creation of a significant market in green bonds requires associated institutional changes in order to establish and monitor rigorous standards for classifying funded projects as green. While the Climate Bond Initiative is committed to achieving such transparent standards, experience with other climate related finance mechanisms suggests that it will be difficult to achieve the degree of standard setting required for a well-functioning market.

Green Bond Issuance Diversification



Source: Shishlov, I., Morel, R. and Cochran, I., 2016. *Beyond transparency: unlocking the full potential of green bonds*. Institute for Climate Economics

Financing decentralised clean electricity

So, can we envisage sub-Saharan Africa being transformed in the near future by decentralised clean power? Among the obstacles that have to be faced is the readiness of unconnected end users to make use of access to a local clean power supply. Adoption of the supply innovation is an example of an issue encountered in more general studies of diffusion of innovations as suggested in an analysis of decentralised clean energy in Uganda. It is at the opposite end of a financing process compared to international finance sources; it involves matters at ground level.

The experience of Brazil suggests possible difficulties, for legislation in 2012 intended to promote small scale (household level) solar energy has not resulted in significant adoption. For African countries, some insight into the challenges facing adoption of local clean electricity can be gained at a granular level from case studies.

Interviews of actors involved in renewables-based local systems in rural areas of Uganda, Tanzania, and Mozambique, including local residents who have had the opportunity to access that electricity have revealed numerous difficulties. They include lack of local management skills, difficulty of ensuring maintenance of installed systems, the need for organisations and individuals promoting the system to obtain local trust, and finance.

Financing installation costs is an obstacle for adoption by households. Evidence from case studies suggests that financial innovations that enable cost recovery while lowering the financial threshold reduces the obstacle to adoption by low-income consumers with low savings for such investment. A range of financial models have been used within African programmes promoting decentralised clean electricity systems models. All use fee-for-service payments that enable adopters to spread the cost in very small, affordable payments related to use.

In Tanzania, Uganda and elsewhere recent 'Paygo' systems use mobile payments systems and remote monitoring. By contrast early fee-for-service systems for decentralised solar electricity in Zambia involved monthly visits by the electricity scheme's company's technicians to collect the fees, check on maintenance and provide a two way channel for information and feedback. The Zambian schemes' success is likely due in part to such 'outreach' – parallel to the experience of microfinance schemes where 'outreach' based schemes outperform others. The outcome of those Zambian cases is also due partly to its subsidy from foreign aid. A case study of South Africa's programme to roll-out household clean power systems with fee-for-service cost recovery through local service delivery enterprises (concessions) operating forms of outreach finds that the programme's success depends on the continuity and predictability of subsidies to the concessions.

Fee-for-service methods of financing decentralised supplies rest on business models where local agents, operating concessions granted by a central authority supply installations and maintenance and recover costs from subsidies and fee-for-service customer payments. Since the long run financial sustainability of that model is not yet known, it is too early to say that it can successfully reduce the obstacles to adoption and have a significant impact on increasing access to electricity.

Conclusion

Considering the current situation of electricity availability and use in sub-Saharan Africa and the prospects for transformation, this article introduces some key concepts and issues. Its limited scope requires the omission of many features and issues in Africa's electrification and the paper contains no direct policy recommendations. At present, the broad policy implication is that policies to address institutional obstacles at different points in the financing process are necessary.

Treating the financing process of electrification at the level of sub-Saharan Africa as a whole obscures the wide variety of national experiences and prospects in the region. It diverts attention from the lessons that can be learned from countries' varied problems and policies.

Within the region's variety South Africa's electricity sector is an outlier not only because of its size and its situation within an industrialised society with large coal reserves, but because of the institutional framework that has enabled long term strategic planning. Notwithstanding faults in corporate and political governance affecting the sector, South Africa's opening of the sector to independent power producers introduced private enterprises that changed the energy mix by producing a significant expansion of clean energy. It is a world-leading example of institutional change – including strategic change in regulations and tendering processes -- facilitating a change in market structure to enable new financing processes and an effective shift in the country's electricity provision.

ELECTRIFICATION IN AFRICA: THE NEED FOR NEW FORMS OF COOPERATION

Lapo Pistelli

The lack of access to electricity is one of the prime structural brakes on development and improved human health in sub-Saharan Africa, and fresh thinking is required to improve a dismal situation and to prevent it from becoming even worse.

The situation is all the more regrettable because the continent has huge renewable energy potential and abundant natural gas – the cleanest hydrocarbon – which, when combined, can deliver stable and environmentally sustainable electricity generation.

Electricity plays a key role in development not only as a primary enabler of industrialization and modernization – powering everything from basic manufacturing to the Internet – but also as a primary driver of the basic well-being of local communities. It can power the efficient pumping of water, refrigeration for food and medicines, and cooking and lighting. Its unavailability for hundreds of millions of people in sub-Saharan Africa means countless early deaths and environmental devastation from cooking indoors with charcoal produced by cutting down scarce trees and using kerosene for both cooking and lighting – not to mention the substantial contribution to economic and social development that women could make if they were freed from gathering biomass for energy.

So far, improvements in access to energy have not substantially changed the overall picture in the region. About 600 million people still have no access to electricity, and according to IEA's World Economic Outlook (WEO) the number will be about the same in 2030 (while it will decrease in all other world regions). In sub-Saharan Africa, the average electricity consumption per capita is between 100 and 200 kilowatt hours (kWh), compared to 2,100 kWh in emerging Asian economies, 5,100 kWh in Europe, and more than 10,000 kWh in the United States. In addition, over the last decade, although Africa's global primary energy supply has grown by more than 3 per cent each year, the energy mix has remained substantially unchanged. The region's electricity-generating capacity has changed little in more than 20 years. At about 0.04 megawatts per 1,000 people, capacity is less than one-third that of South Asia, and less than one-tenth that of Latin America and the Caribbean. Whatever general progress there has been in Africa has been propelled by improvements in East Africa, where the electrification rate increased by roughly 30 per cent to reach 40 per cent in 2016. In 23 of the 42 countries of sub-Saharan Africa, however, more than 90 per cent of the population uses only biomass (mostly charcoal) for cooking and heating.

The untapped potential of natural gas

Natural gas has a large untapped potential; it currently meets only 13 per cent of demand. Gas reserves are often not developed because they are commercially unviable – the reserves are too small, national legislation is not conducive to investment, domestic prices are subsidized and thus provide inadequate return on investments, or the off-takers have creditworthiness issues. Even when gas is associated with oil production, the same problems arise, and flaring – burning gas associated with oil production into the atmosphere – is still very common. The amount of gas burned each year in Africa is equal to 30 per cent of the total gas consumption of the continent.

All this has led to the sad fact that, according to the World Bank's *Private Participation in Infrastructure Report 2017*, in Africa in 2017 all new power plants burned fuel oil, diesel, or even coal, thereby both losing an important bet on the continent's energy transition and placing a heavy burden on national budgets.

So the market alone is failing to deliver access to energy in the sub-Saharan region. Natural resources are there, as well as actual and potential energy end-users. Fixing what is missing or not properly functioning requires a vast joint effort between governments, international institutions, and the private sector to bring together government development goals with private-sector know-how, technology, and capital.

The experience in Ghana, the only country in sub-Saharan Africa in which non-associated gas has been developed in deep water and entirely dedicated to the domestic market, is a good example of a model that could be more frequently applied. The Offshore Cape Three Point (OCTP) block, of which Eni is the operator, is located about 60 km off Ghana's Western Region coast. The fields have about 770 million barrels of oil equivalent (MBOE) in place – 500 million barrels of oil and 270 MBOE (about 40 billion cubic meters) of non-associated gas. Eni started gas production from OCTP in early July 2018. The field is expected to provide 180 million standard cubic feet per day for at least 15 years, enough to convert half of Ghana's power generation capacity to gas. Production will gradually flow via a dedicated 60 km pipeline to the Onshore Receiving Facility in Sanzule, where gas will then be compressed and distributed to Ghana's national grid. OCTP gas will contribute to Ghana's energy stability, which is a prerequisite for industrial and economic growth, while at the same time helping reduce harmful emissions.

Development of the gas resources was made possible by the negotiation of an innovative payment security structure involving World Bank (International Bank for Reconstruction and Development and International Development Association) guarantees amounting to $700 million: $500 million from the International Development Association to secure payments by the state-owned Ghana National Petroleum Corporation for the purchase of gas, and $200 million from the International *Bank* for Reconstruction and Development to cover the repayment of the loan. The World Bank's involvement also paved the way for subsequent participation by international commercial banks and export credit agencies as well as the International Finance Corporation and the Multilateral Investment Guarantee Agency.

Obtaining a credit enhancement guarantee is not an easy task. Only multilateral development finance institutions such as the World Bank and the African Development Bank can provide these. Guarantees are rightfully subject, among other things, to a country's effective implementation of policy reforms that ensure that the power sector is able to sustain itself. The duration of these processes and their unpredictability discourage investors, leaving significant national resources untapped.

The European Union (EU) has also recently launched a guarantee scheme under the EU External Investment Plan. The European Fund for Sustainable Development will underwrite loans, guarantees, or 'any other form of funding or credit enhancement' offered by trusted institutions, such as development banks, governments, and private companies investing in development projects in Africa or in the EU's southern and eastern neighbour countries. Unfortunately, investments in gas-fired power plants have not been considered a primary target for the European Fund for Sustainable Development.

A good model could be the Scaling Solar programme, designed by the World Bank Group to help create viable markets for grid-connected solar photovoltaic (PV) power plants in low-income countries. The programme offers a one-stop-shop package of advisory services, contracts, financing, guarantees, and political risk insurance from the World Bank, International Finance Corporation, and Multilateral Investment Guarantee Agency. Both International Development Association payment guarantees and loan guarantees are offered to developers. The programme is currently active in Ethiopia, Madagascar, Senegal, and Zambia. It has been able to attract top-tier global developers and, through the provision of guarantees, to make power available at very low tariffs.

New forms of cooperation

This points to the importance of developing new forms of cooperation between the private sector, development finance institutions, and the public sector. For instance, steps taken by the EU in further expanding the use of guarantee schemes in the new budget proposal for the EU External Action, envisaged for the next Multiannual Financial Framework (2021–2027), will hopefully consolidate and expand the approach inaugurated by the European External Investment Plan launched in 2016. There is great potential for EU guarantee schemes to encourage private-sector funding and address suboptimal investment situations, provided that simplification and streamlining across the financial institutions involved in the scheme are ensured.

There is also great potential in the African Investment Forum and the initiative that the African Development Bank is leading to set up a 'mutualized co-guarantee platform' to de-risk investments, together with the International Finance Corporation, World Bank, Inter-American Development Bank, Islamic Development Bank, and European Bank for Reconstruction and Development, among others.

In short, to build a future where everyone can access energy resources efficiently and sustainably, collaborative effort that helps de-risk investments in the electrification of Africa is key.

NATURAL GAS IN NIGERIA AND TANZANIA: CAN IT TURN ON LIGHTS?

Rahmatallah Poudineh and Tade Oyewunmi

Nigeria and Tanzania are two countries in sub-Saharan Africa (SSA) in which natural gas is likely to remain essential for meeting growing energy demand in the medium to long term. Nigeria has the most abundant gas reserves in Africa and has been the continent's leading producer for several years. Tanzania, on the other hand, has made significant gas discoveries within the past decade. The two countries are keen to leverage their abundant gas reserves to boost electricity generation and energy access for industrialization and economic growth.

There are various reasons that gas is considered a strategic option in electrification. First, the modular investment costs of gas-fired generators make them attractive to investors, especially when there is an adequate infrastructure and reasonably priced gas supply outlook. Second, natural gas is the cleanest-burning hydrocarbon and is often portrayed as a bridging fuel that can provide security and reliability in increasingly decarbonized economies where renewable energy sources are becoming dominant. Third, advancements in combined cycle gas turbine technology realised over the past two decades means that power generation is now more efficient in terms of energy and heat utilization. Therefore, the successful development of gas-to-power supply chains in these countries has the potential to contribute to both energy access and decarbonization.

Developing a commercially viable gas-to-power supply chain is, however, a complex matter for both countries. The main issues in Nigeria are

- inconclusive structural reforms and lack of an independent regulatory regime for domestic gas supply,
- poor geographical coverage of gas transportation pipelines between the gas-rich south-south Niger Delta region and the main generation facilities which are nearer to industrial and commercial centres in the western and eastern region,
- misalignments between institutional and commercial developments in the gas sector and electricity supply industry even as the latter was privatized and being liberalized (Oyewunmi 2018),
- an unstable power transmission network, and
- a liquidity crisis in the Nigerian power sector due to high energy losses, exacerbated by non-cost-reflective tariffs and irregular bill collection (Peng and Poudineh, 2017).

In Tanzania, which has ambitious electrification plans, enhancing the gas-to-power supply chain requires not only timely investment in generation capacity but also an increase in gas production and processing. Given the small scale of onshore reserves, Tanzania will need to invest in its offshore gas resources for domestic use; this is challenging as it requires technical expertise and capital from international oil companies, who typically prefer export rather than domestic supply mostly due to the often distorted gas prices in the domestic market. The liquidity crisis of the Tanzania Electric Supply Company (TANESCO), the state utility company, and the high level of technical and nontechnical energy losses in the electricity grid further exacerbate these issues (Peng and Poudineh, 2016).

These issues are arguably the reason that gas consumption for power generation is much lower in Nigeria and Tanzania than in the resource-rich North African countries as shown in the graph.

Nigeria

Although it has about 184 Trillion Cubic Feet (Tcf) of proven reserves, Nigeria produced about 47.6 Billion Cubic Feet (Bcf), 42.6 Bcf, and 47.2 Bcf of gas in 2015, 2016, and 2017, respectively (BP Statistical Review of World Energy

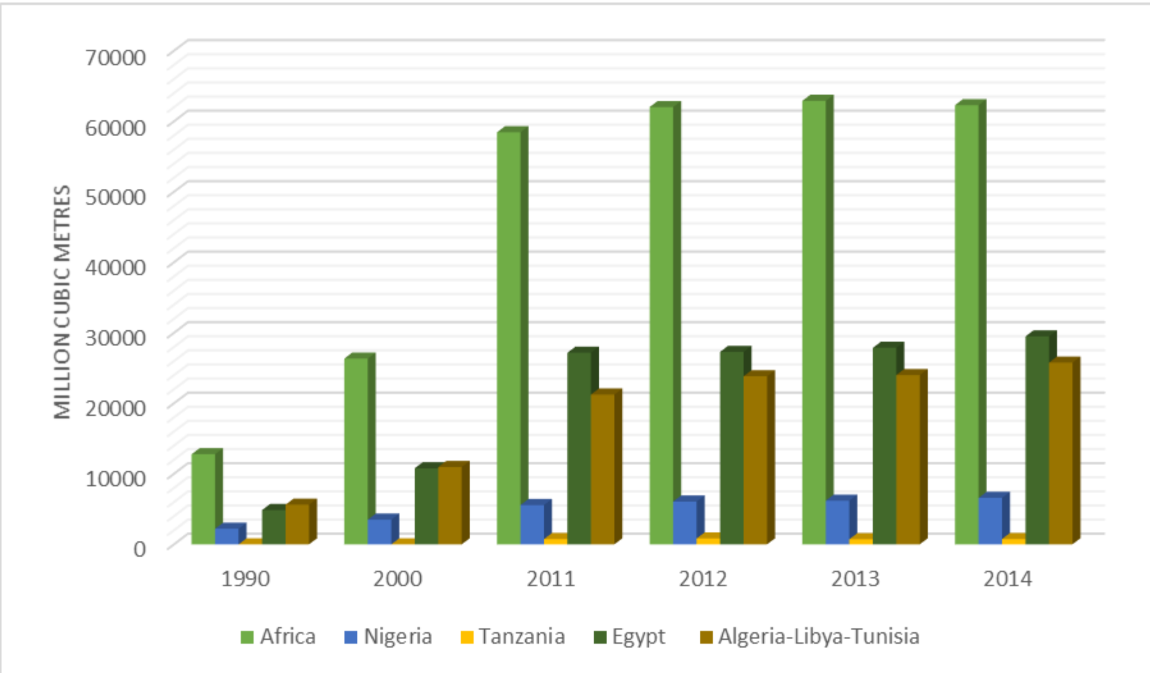
2018). Most of the production is typically either exported as Liquefied Natural Gas (LNG) and Natural Gas Liquids (NGL), reinjected as part of enhanced oil recovery processes, or flared (NNPC Bulletin). Despite this, natural gas has been the primary fuel for power generation in Nigeria, which has a total installed capacity of about 12,522 megawatts (MW) (10,142 MW thermal and 2,380 MW hydro) (see Power Africa). In 2013, the nation's primary energy consumption consisted of 74 per cent biomass (typically wood, charcoal, manure, and crop residues, used for cooking and heating, mainly in rural areas), 12 per cent natural gas, 13 per cent oil, and 1 per cent hydro (US Energy Information Administration (EIA)).

Nigeria's population is about 186 million, and the electrification rate is about 45 per cent, leaving tens of millions of people without access to electricity (US EIA). This means Nigeria has one of the lowest rates of net electricity generation per capita in the world. Those with access to electricity often face blackouts and interruptions in service due to load shedding, and thus mostly rely on self-generation through private diesel and petrol generators. To address electricity shortages in Nigeria, the immediate past government set a target of 20,000 MW of generation capacity by 2020, while the current government is pursuing incremental additions to generation capacity. The Nigerian Electricity Regulatory Commission's (NERC's) regulations and guidelines for captive power generation, embedded generation, independent distribution networks, mini-grid permits, and renewable-energy-sourced electricity helps to outline a cognisable framework for much needed capacity additions, including off-grid systems. The structural reforms of the power sector launched in the early 2000s led to (i) the establishment of the NERC as independent regulator, and (ii) the corporatisation and unbundling of the vertically integrated state-owned utility i.e. the Nigerian Electric Power Authority, into six generation companies (GENCOs), 11 distribution companies (DISCOs), and a national transmission company. The privatisation of the GENCOs and DISCOs was completed in 2013.

Currently, power generation from about 25 grid-connected generators (21 gas-fired thermal power plants and 4 hydro-powered) are mostly constrained due to shortages and interruptions in gas supply, while power generation from the hydro generators fluctuates with seasonal changes and rain levels. The 25 grid-connected generators are owned and operated by the GENCOs, independent power producer (IPPs), and the National Integrated Power Project (NIPP) plants. The NERC reports that, as of June 2018, only 5 power purchase agreements (PPAs) were fully active, and only 3 gas supply agreements (GSAs) were fully active, out of which two were self-suppliers, Shell Petroleum Development Company of Nigeria (SPDC)'s AFAM VI, and Okpai IPP, owned by the Nigerian National Petroleum Corporation (NNPC)/Agip Joint Venture. (For information from the NERC on PPAs and GSAs, (see here).

One major reason for nonactivation of take-or-pay-based gas supply

African gas consumption for power generation, 1990–2014



Source: International Energy Agency, Natural Gas Information, 2016 Edition agreements, which also underscores the liquidity challenge in the gas-to-power supply chain, is reported to be the inability of the Nigeria Bulk Electricity Trading Company (NBET) to meet its payment obligations to the GENCOs. In the current transitional energy market context, NBET was created to purchase electricity from the GENCOs, NIPP and IPPs, based on the PPAs and sells to DISCOs through vesting contracts.

In an extended gas-to-power supply chain, energy travels from gas upstream to electricity downstream while money moves in the opposite direction. However, in Nigeria, final electricity tariffs are generally non-cost-reflective, and this creates financial problems for the entire gas-to-power supply chain. Since 2015, every change in the electricity tariffs has encountered opposition from either DISCOs or end-user representatives. The trend is exacerbated by an irregular bill collection regime, which is still mostly based on estimates or analog meter readings, while few end-users have access to digitalised or smart meters. Records from the Port Harcourt Electricity Distribution Company, submitted as part of the latest tariff review, reveal that residential customers are the source of the most significant collection losses, with only 43 per cent of all bills collected, compared to 77.4 per cent for commercial customers and 75.3 per cent for industrial customers (Peng and Poudineh, 2017). A survey of low-income consumers revealed irregularities at the distribution and demand interface: many low-income consumers did not know the name of their DISCO and had never interacted with them; most customers were unmetered and thus wrongly classified and received estimated bills; the prevalence of estimated billing has led to illegal bill collection rackets, resulting in voluntary disconnection of customers (who may continue to be billed based on estimations). Current measures of aggregate technical, commercial, and collection losses for the 11 DISCOs range between 30 and 60 per cent, though a detailed breakdown of losses across categories is not available. This has resulted in a liquidity crisis across the gas-to-power supply chain. The insolvency and commercial issues faced by the utility companies has impacted their ability to carry out timely investment in generation capacity and electricity network enhancement.

In the gas sector the transmission and distribution networks do not have sufficient coverage. Additionally, the regulation of pricing for gas supply to power below cost-of-service has, among other things, had a negative impact on investment decisions and market development. The current domestic gas pipeline infrastructure mainly comprises two unintegrated pipeline networks of approximately 1,100 kilometres: the Alakiri-Obigbo–Ikot Abasi Pipeline (the Eastern Network), and the Escravos–Lagos Pipeline System (the Western Network), as well as the dedicated pipeline infrastructure owned by the Nigerian Liquefied Natural Gas Company, the NNPC/SPDC/Total Joint Venture, and the Chevron/NNPC Joint Venture. The Eastern Network is limited in reach, while the Western Network delivers gas to Lagos, the main commercial nerve centre and most populous state in Nigeria. For over a decade, several planned but uncompleted pipeline and gas processing facilities have been earmarked by NNPC and the Federal Government under the Nigerian Gas Masterplan's Gas Infrastructure Blueprint.

Protracted reforms in the oil and gas industry and attendant institutional issues in the gas-to-power supply chain context adds another layer of complexity (Oyewunmi, 2017). The government seemingly recognizes the need for developing good quality and effective framework to address the longstanding challenges that arise beyond gas production. Among other things, the proposed plans and policy objectives aim to facilitate the development of a liberalised market for gas-to-power in the medium to long-term and also set up an independent economic regulator in the context of the wider petroleum industry reforms (National Gas Policy, 2017). Despite the lack of a coherent regulatory framework for downstream gas transmission and distribution (legal reforms in this area have continuously stalled), there are private companies engaged in gas transmission and supply to a few large industrial and commercial buyers. However, such suppliers still need to rely on existing infrastructure mainly owned and operated by the NNPC and its gas transmission subsidiary.

The proposed legal and institutional reforms of the National Oil and Gas Policy 2004 and the Petroleum Industry Bill, and re-drafts such as the Petroleum Industry Governance Bill (PIGB) 2017, have been inconclusive. The PIGB was recently passed by the National Assembly but requires presidential assent before it becomes law, and this appears unlikely before the 2019 presidential elections. The implementation of the National Oil and Gas Policy, the Gas Master Plan 2008 (which provides for a gas pricing policy, the Domestic Gas Supply Obligation (DGSO), and the Gas Infrastructure Blueprint), and the 2008 National Domestic Gas Supply and Pricing Policy and Regulations, all within the ambit of the Petroleum Act 1969, NNPC Act 1977 and Oil Pipelines Act 1956, have been largely ineffective. Problematic provisions in the policy documents include requiring the delivery of low-cost gas to the power market, while not properly defining ‘low cost’ or enabling the commercial environment to make such volumes available; lack of clarity and duplication in the roles of the new gas aggregator (the Gas Aggregation Company Nigeria), the Department of Gas, and the Department of Petroleum Resources (DPR); as well as the extensive powers of the Minister of Petroleum, a position that under some circumstances is filled by the President (Oyewunmi, 2014). Since the DGSO policy was adopted in 2008, there has been a dismal level of compliance by upstream producers, including the NNPC and its upstream joint venture interest holders or production sharing contractors, comprising of international and local private companies (National Gas Policy, 2017). The main reasons for non-compliance with DGSOs can be attributed to inadequate infrastructure, cost inefficiency, economic and price regulation issues as well as supply disruptions and sabotage of pipelines in the Niger-Delta area. Notably, the issue of sabotage and militant disruptions has reduced considerably within the past three years, following definite steps taken by the current federal government on security issues. Going-forward, it will be essential to address the misalignments between the power sector’s costs, tariff setting, and market dynamics vis-à-vis developments in gas supply industry.

Among other things, the federal government recently approved two policy instruments under its National Economic Recovery and Growth Plan 2017-2020 i.e. the National Gas Policy 2017 and the National Petroleum Policy 2017. The National Gas Policy recommends a single, industry-wide regulatory agency i.e. the Nigerian Petroleum Regulatory Commission, while the Ministry of Petroleum will remain responsible for policy directives and supervision. The NNPC is earmarked for restructuring and privatization once the required laws to consolidate the policy proposals are enacted. Domestic market requirements are to be prioritized, while Nigeria seeks to maintain a significant presence in international markets.

On pricing reforms, the 2017 National Gas Policy stipulates that the upstream gas price for domestic sales will be fixed based on netback from export parity prices. Thus, the price an upstream producer will receive for supplying gas to the domestic market will be set at par with the average price received by producers for exporting gas, less the cost of transportation or delivery to the export destinations. The rationale is to develop a cost-reflective pricing regime to encourage producers to supply gas locally or at least be neutral in choosing between the domestic market and often more favourable export markets. The setting of tariffs is to be based on a regulated cost of service and rate of return paradigm, with an eventual transition to a fully competitive and liberalized wholesale market (National Gas Policy, 2017).

While the provisions of the National Gas Policy are seemingly on the right track, it is perhaps more important to resolve the underlying administrative, institutional, and structural issues that may have hindered the timely completion of infrastructure projects and created funding and investment gaps. There is also a need to deal with regulatory uncertainties, duplication of roles, and liquidity issues affecting the creditworthiness of gas offtakers in the gas-to-power supply chain (Peng and Poudineh, 2017; Oyewunmi 2018).

Achieving the goal of a gas-fired power generation capacity of over 20,000 MW by 2020 appears unrealistic, considering the amount of investment, institutional efficiency, and infrastructure development that would require (see here). Attaining this ambitious target will require more than doubling the current daily domestic gas supply. Developing the reserves required for such an increase in domestic supply, estimated at 30 Tcf, will require timely capital investments of US$20 billion or more. The difficulties in arriving at a market-led or cost-reflective price for gas-to-power, largely due to the socio-political challenge of managing pass-through costs and transitional issues, have created a very complex challenge.

From an efficiency perspective, rationalizing gas prices is necessary, but in theory, it might give a competitive advantage to more carbon-intensive fuels such as coal. Coal played a considerable role (mostly in commercial applications and rail transport) between 1906 and 1960. However, after the discovery of commercial oil reserves in 1956, the share of coal in the Nigerian energy mix became negligible. It reportedly dropped to about 0.02 per cent or less by 2003. Although Nigeria is reported to have about 639 million tonnes and 2.75 billion tonnes of proven and inferred reserves of coal, respectively, its use for power generation faces daunting challenges. These include the high cost of reopening and increasing the productivity of the coal mines, the need for mechanization and ancillary transportation systems, and most importantly, the environmental factors that make coal less popular than renewables such as solar and wind. Recent gas-fired IPPs such as Azura-Edo and initiatives for distributed and incremental generation, especially with renewables (in particular solar), suggest that investors are willing to invest in both gas-to-power and renewables. However, institutional and governance issues need to be addressed, and a transition to a more competitive and commercially viable gas-to-power pricing system needs to occur in the mid to long term.

Tanzania

With around 55 Tcf of natural gas reserves, Tanzania is emerging as a major gas producer in SSA. Its other energy resources include 1.9 billion tonnes of coal, of which 25 per cent is proven, a potential for about 4,500 MW of hydro, with just 12 per cent currently developed, and other renewable sources like solar and wind (Energy Policy 2015). Electricity net generation in Tanzania was 5.3 billion kilowatt hours (kWh) in 2013, of which almost 68 per cent was from fossil-fuel sources, 32 per cent from hydropower, and a small amount from modern biomass and solar (US EIA). Akin to Nigeria, Tanzania's rural population relies on traditional biomass and waste (typically consisting of wood, charcoal, manure, and crop residues) for household heating and cooking.

Tanzania's economy has also grown rapidly over the last 10 years. The gross national income per capita increased on average by 9.5 per cent each year between 2006 and 2014, from $450 to $930. Per capita electricity consumption grew from 51 kWh to 99 kWh between 2000 and 2012, at an annualized growth rate of 6 per cent, but it remains low relative to other countries with similar levels of total energy consumption. To increase the use of electricity, the government has established aggressive electrification targets: 30 per cent by 2015 (which has already been achieved), 55 per cent by 2025, and at least 75 per cent by 2035. Although this is less ambitious than the United Nations' goal of universal access to modern energy services by 2030, it is aligned with estimations that SSA is more likely to achieve an electrification rate of 80 per cent by 2040, based on experiences elsewhere such as Tunisia, South Africa, Indonesia, and Brazil.

TANESCO, the state-owned utility company, currently owns and operates downstream power sector infrastructure. Mwenga Hydro, which owns and operates the 4 MW hydro project, is the only other company that also holds a licence for distribution and supply activities. The main grid owned and operated by TANESCO consists of 4,869 km of transmission lines at 220 kilovolts (kV), 132 kV, and 66 kV.

The installed generation capacity in Tanzania includes both on-grid and off-grid facilities. Of the on-grid facilities, hydropower stations (561 MW of hydropower projects commissioned between 1964 and 2000, dominated by the Kidatu Dam with 204 MW and the Kihansi Dam with 180 MW), are responsible for about half of the electricity generated in the country. These hydro stations are located in southern Tanzania, while most load centres are in the north. There are also fossil-fuel-fired, on-grid power generating plants built since the 2000s, owned and operated by different companies, reflecting the lifting of TANESCO's monopoly in generation starting in 1992. Fossil-fuel-fired generation plants owned and operated by IPPs came online a decade after the lifting of the monopoly: Independent Power Tanzania in 2002 and Songas in 2004. In 2011, TANESCO contracted emergency power producers, the US company Symbion Power and Glasgow-based Aggreko, to bridge the electricity supply gap caused by droughts and to provide diesel-fired rented capacity. Since 2010, a few small power producers have provided electricity to the grid from biomass and hydro plants.

In regions where connection to the grid is not available, mainly in the western belt from Bukoba to Songea, TANESCO owns and operates isolated diesel-generator-powered mini-grids. Mini-grids on the eastern shore, in Somangu and Mtwara, operate small gas-fired power plants which are supplied by natural gas from the Songo Songo and Mnazi Bay projects. Some contracted small power producers also provide electricity to the mini-grids. A further 15 MW of generation capacity is available through imports from Uganda and Zambia, exemplifying the growing importance of cross-border energy supply transactions in SSA.

The government of Tanzania also plans to expand the country's installed gas-fired generation capacity. The plan includes four major plants: the 150 MW Kinyerezi I, funded by TANESCO and started in 2016; the 240 MW Kinyerezi II, which started operation in 2018 with a capacity of 168 MW but is expected to reach full capacity later; Kinyerezi III, with 320 MW in phase 1, to be financed by China Power Investment Corporation; and Kinyerezi IV, with 330 MW capacity in phase 1, to be financed by China's Poly Group, a state-run conglomerate.

Beyond these projects, the Symbion Southern Electrification Project, a 400 MW gas-fired power plant and a 400 kV transmission line from the plant in Mtwara to Songea, is being negotiated as a public–private partnership between TANESCO and US-based Symbion Power, a company already operating in Tanzania as an emergency power producer. There are also plans to install other types of plants such as small-scale hydro, biomass, solar photovoltaic, and wind power.

To achieve its gas-to-power strategy, the government of Tanzania needs to deal with several key issues. The first is ensuring adequacy of gas supply and timely investment in upstream facilities. The planned capacity of gas-fired generation is 1,700 MW, which, in combination with existing gas-fired generation capacity of 736 MW, amounts to a total of 2,436 MW if all planned power plants come online on time. If run at 70 per cent load (the average load factor of Tanzanian demand) and assuming a higher heating value-based efficiency of 40 per cent, supplying all these power plants will require a gas supply of 340 MMcf (Million Cubic Feet) per day. Estimates from TANESCO, using different assumptions, forecast a 2018 demand of 475 MMcf/day. Existing production capacity is 102 MMcf/day at Songo Songo and 70 MMcf/day at Mnazi Bay, adding up to 172 MMcf/day, which falls short of the projected demand. Based on the $120 million cost of expanding production at Songo Songo from 92 MMcf/day to 102 MMcf/day, the expansion still needed (from 160 to 300 MMcf/day) is likely to require investment of $2 billion to $3.5 billion. The existing gas transmission capacity between the production fields and the proposed locations for the power plants, the Mnazi Bay–Dar es Salaam pipeline, has a total capacity of 784 MMcf/day, which is adequate and not expected to require expansion in the near term.

The second challenge for the Tanzania government is that the total near-shore reserve, estimated at 2,147 Bcf, will only be able to support consumption by power generation plants at the planned rate for 17 years. If gas-fired plants are to supply Tanzania beyond 2035, the off-shore reserves will need to be developed by that time. The capital investments and technical capacities of international oil companies are expected to be of critical importance for this purpose. However, such involvement is largely conditional upon the development of the onshore LNG export facility, projected to cost between $20 billion and $30 billion. A portion of the gas produced by the international oil companies will be used to supply the domestic market under the domestic supply obligation contained in their production-sharing agreements.

Thus, the success of the investment plan for enhancing the gas-to-power supply chain in Tanzania depends not only on timely investment in generation capacity, but also on timely investment to double gas production and processing at Songo Songo and Mnazi Bay. In the long term, it also depends on the successful development of Tanzania's offshore gas resources for domestic use, which is unlikely to occur independently of an export LNG project.

On top of these issues, Tanzania suffers from high energy losses; these stood at 18 per cent in 2012. Although its transmission and distribution losses are comparable to those of its neighbours (Zambia, Kenya, and Mozambique), they are significantly higher than the world average. A portion of these losses are due to technical problems: ageing infrastructure, unplanned extension of distribution lines, and the overloading of inadequate equipment. About half is also due to commercial problems such as misalignment between billed electricity and electricity fed to the power grid.

TANESCO has announced plans to invest in transmission capacity with the goal of integrating the gas-producing south with the main grid. This should reinforce the transmission backbone around and to the west of Dar es Salaam, and expand the grid towards inner Tanzania, where isolated diesel-powered mini-grids operate. However, TANESCO has been facing serious liquidity issues, which constrain its ability to make significant investments. Furthermore, TANESCO's liquidity problems and the high transmission and distribution losses reportedly threaten the operations of IPPs and negatively affect their willingness to invest. TANESCO's costs of service are subject to critical external uncertainties like hydrology, currency depreciation, and global fuel prices. To become fiscally sustainable, the regulator needs to periodically adjust retail tariffs based on ex-post fuel costs and inflation rates. However, this diminishes its ability to maintain tariff stability, which might impact certain classes of customers more than others.

In view of the challenges of gas-to-power in Tanzania, the government has also been considering coal as a fuel to enhance energy access. In 2013, Tanzania produced about 77,000 tonnes of coal, which was consumed locally (US EIA). Kibo, a Tanzania-based minerals exploration and development company, is undertaking a twin-track development at Mbeya, comprising a coal mine based on the existing coal resource and a 250–300 MW mouth-of-mine thermal power plant which has an engineering, procurement and construction (EPC) contract with a China-based contractor. In recent years, China, as part of its Belt and Road initiative, has exported coal power plants to Africa. Despite these, the market and institutional and infrastructural capacity for significant coal utilization is still underdeveloped compared to gas-to-power. Thus, as in the case of Nigeria, significant new investment in coal power plants is more problematic than investment in gas fired plants and ancillary gas supply infrastructures. Furthermore, under current project financing conditions, it is becoming more difficult to secure international investment in coal utilization. International investors and multinational financing institutions are seemingly more receptive to clean generation, especially due to climate change concerns and the global drive for decarbonisation.

Conclusions

A viable gas-to-power market in Nigeria and Tanzania has the potential to contribute significantly to universal energy access and to the security and sustainability of the energy supply. However, the development of a competitive and commercially secure gas-to-power supply chain is a complex task.

For Nigeria, the main concerns are the effectiveness of legal and institutional reforms in the power and gas sectors; the need for an independent regulator of the domestic gas supply; timely investment in and completion of essential infrastructures; efficient management of the costs and benefits of transitioning to a more liberalized and market-led gas to power system; the reliability and resilience of the power transmission network; and the liquidity of the power sector.

For Tanzania, achieving gas-to-power objectives requires timely investment in generation capacity and development of gas reserves upstream. There is also a need to leverage the technical and operational expertise of international oil companies for offshore reserves, both for export projects and to meet domestic requirements. Addressing TANESCO's liquidity crisis will require considerable economic and structural reforms.

The two countries now have a clear path towards maximizing gas utilization for power generation with an understanding of underlying pricing and governance challenges. Such understandings are increasingly leading to economic restructuring and new policy instruments intended to support the transition to a liberalized and competitive gas-to-power market. Renewables already play a significant role in Tanzania, and their use is growing in Nigeria. Looking-ahead it is expected that renewables fill the gaps created by inadequate gas-to-power infrastructure and provide energy access in remote and rural areas.

NEW ENABLERS FOR ACHIEVING SUSTAINABLE ENERGY FOR ALL IN AFRICA

Carlo Papa and Giuseppe Montesano

At the beginning of the last century in the north-western United States, electricity salespeople were following the farmers who were turning the desert green, and new distribution lines were following the salespeople. At about the same time, in Italy, the economy was growing at double-digit rates year on year, powered by the 'white coal' of hydropower.

In both cases, our predecessors bet that electricity would play an essential role in economic development – considering electricity, at the very least in the access and development phases, a cause or a facilitator rather than assuming a unidirectional causal link from economic growth to electricity availability – and bet even more on humans' ability to become smarter masters of nature through lateral thinking.

In July 2018, United Nations Secretary General António Guterres will report to the High-Level Political Forum on Sustainable Development on progress towards the Sustainable Development Goals (SDGs), providing an overview of the current situation for each SDG. Commenting on progress on SDG 7 (ensure access to affordable, reliable, sustainable and modern energy for all), he will likely highlight that 'ensuring access to affordable, reliable and modern energy for all has come one step closer due to recent progress in increased access to electricity, particularly in Least Developed Countries (LDCs) and improvements in industrial energy efficiency'. Still, the report will draw our attention to the nearly 1 billion people who still lack access to electricity, a good portion of whom live in Africa. Surely, looking at this figure, we should avoid an overly pessimistic view and recognize the substantial progress that has been made. However, we must stress the need to find new and more effective ways to achieve sustainable energy for all (see here) in Africa, focusing on an integrated way to address the economic, social, and environmental dimensions of sustainable development.

In this context, we should be ready to bet once again, as our predecessors did, on electricity and on the capabilities of human beings by recognizing that humanity has the potential to develop in a sustainable way within the operating space of planetary boundaries (*The Human Quest: Prospering Within Planetary Boundaries.* Johan Rockström, Mattias Klum, 2012). This time, after a century of experience, it should be easier, given the evidence of the relationship between electricity and growth – to the extent the UN identifies access to sustainable energy as a prerequisite for poverty eradication and building the sustainability and resilience of communities – and the tremendous progress made on renewable generation and smart grids able to function as platforms for global and local sustainable development.

The human factor is indeed the indispensable element – and sometimes the most forgotten – to some extent, the real compass in the journey from poverty to sustainable prosperity in the realm of electricity.

We need to keep in mind our fellow human beings, their needs, and their competences in a given lifespan, when thinking about strategic and practical approaches to generation and supply of electricity in energy-deficit areas of the planet. We should consider what people need in order to thrive, with electricity as a key element – rather than setting a theoretical level of demand based on the assumption that people in energy-deficit regions cannot expect a similar level of energy supply, and well-being, as people in energy-surplus regions. Undeniably, this requires us to design growth paths and set development milestones relying on and implementing, from the beginning, scalable solutions to accommodate growing energy needs in a sustainable and resilient setting.

Two megatrends have a direct impact on electricity access in Africa. Escalating birth rates and higher life expectancy are rapidly increasing the continent's population, exacerbating existing problems such as youth unemployment and unsustainable social services. Even if electrification efforts in sub-Saharan Africa are accelerating and the number of people without access to electricity decreased for the first time in 2014, these achievements will likely soon be overtaken by population growth.

Urbanization is the other social phenomenon that will significantly influence access to electricity: by 2030, more than 50 per cent of the population of Africa will be living in cities, and by 2050, over 60 per cent. Urbanization is creating significant opportunities for social and economic development and more sustainable living but is also putting pressure on infrastructure and resources, particularly energy.

For a smart, strategic, human-centred approach to electrification, and to achieving sustainable energy for all in Africa, we may want to consider new enablers in three fundamental areas: technical design, business model, and financing.

Technical design

Two possible technical solutions should be considered: utility-scale projects connected to the national grid to provide electrification for most of the population living in the towns or nearby, and decentralized solutions for remote rural areas. Analysis by the International Energy Agency (IEA) revealed that from 2000 to 2016 nearly all of the people who gained access to electricity worldwide did so through new grid connections, mostly with power generation from fossil fuels. Nevertheless, the technologies used to provide access have started to shift, with renewables providing 34 per cent of new connections since 2012, and with off-grid and mini-grid systems accounting for 6 per cent.

India's success story is a good example. Thanks to investment in grids and to new connections realized by the government over the last two decades, electrification grew at a significant rate, increasing the number of people with access to electricity from half a billion to one billion. The commitment of political institutions made it possible to massively improve the quality of life of the population and put India on track to reach universal electricity access in the early 2020s, with renewables providing energy to 60 per cent of the population that gains access.

Even though the Indian contexts differ in some ways from the African ones, including population density, Africa's strong urbanization trend makes access through power plants connected to the grid the main solution. The role of decentralized systems, on the other hand, will be fundamental where scattered populations and remote locations make construction and maintenance of grids difficult, or as a temporary solution prior to grid connection.

This approach can help resolve the debate between advocates of mini-grids and those who argue that, although they may be cost-effective for small and isolated communities, they cannot provide the economies of scale and the resilience of utility-scale smart grids. In powering energy-deficit areas of the planet, we should approach mini-grids as building blocks, applying the lego bricks logic. Practical implementation of this approach is currently rare, if not nonexistent, so it would require a change in perspective, but it could be successful because of its scalability. Gradually connecting mini-grids could help to systematically expand energy access, progressively offering growth opportunities and local benefits with the eventual goal of connecting areas to large grids wherever possible.

Developing and implementing standardized mini grid solutions, using compatible equipment as highlighted by IEA – from analytical site selection tools that help ensure consistency and impact, to software and hardware – could in the short-term help drive down costs, ensure homogeneous quality standards across territories while in the medium term help large smart grid intensification and expansion.Clearly, a positive policy and regulatory environment that recognizes and promotes this electrification solution will create momentum and stimulate new entrants, such as traditional distribution companies, to the micro- and mini-grid space. This is happening in Colombia, where Codensa, part of the Enel Group, has just installed a standardized off-grid system and is planning to reach thousands of households in the near future.

Business model

Conventionally, power generation is seen as a technical component totally integrated into the mini-grid. We could instead consider decoupling it from the mini-grid system, restricting the latter to distribution and supply to end-users, while sourcing power from bigger renewable power plants built nearby serving more than one mini-grid. This approach could benefit from the presence of renewable plants, mostly in semirural areas, often relatively large installations connected to larger grids, which now represent a significant portion of annual capacity additions. It would allow mini-grid customers, who would otherwise be excluded from connection to the larger grid, to enjoy lower electricity costs, mini-grid operators to provide a higher level of service, and the entire community to experience greater resiliency. Last but not least, it would result in a more flexible consumption profile with room to grow over time. Such growth opportunities can serve several productive and social uses, increasing the ability of new customers to pay tariffs and therefore supporting the recovery of investments in grids and increasing their profitability over time.

Financing

International agencies frequently refer to the tremendous amount of investment needed to power rural Africa and the difficulty of raising capital for this purpose. As the electricity sector has evolved over time, transmission and distribution have probably been among the most stable and lucrative segments of the value chain over the medium and long term – to the point that they have become an important element of infrastructure investment, an alternative asset class able to reduce portfolio volatility and gather interest for pension funds, insurance companies, and sovereign wealth funds.

In this context, in a scenario where committed and forward-thinking actors will be able to create clusters of projects, from mini-grid to industrial-scale renewables and grid lines, which can be increasingly integrated with one another, and systematically scale up the electricity system in Africa, we believe there will be ample room for both venture capital and private equity, through which pension funds can invest in powering Africa, receiving the benefit of diversification in the short run while establishing a path to traditional infrastructure deals in the long run. Clearly, this scenario is more likely to materialize where there is a clear institutional framework and a robust regulatory environment.

Conclusion

To ensure that smart grids and renewables become increasingly important elements in the effort to provide energy for all, adopting the operational approaches described above, human-centred and conscious of planetary boundaries, the name of the game is indeed convergence. Reaching consensus among communities on the type of future they want is paramount, as well as tight cooperation between government, local, and international institutions, to ensure that a clear policy framework and robust regulatory environment are in place that encourage all stakeholders to make mutually beneficial choices in enlightened self-interest.

OPPORTUNITIES AND CHALLENGES IN ACHIEVING UNIVERSAL ELECTRICITY ACCESS IN SUB-SAHARAN AFRICA

Anteneh G. Dagnachew, Paul L. Lucas, Andries F. Hof and Detlef P. van Vuuren

Access to electricity is an important prerequisite for human development. This was acknowledged by the global community through the adoption of the Sustainable Development Goals (SDGs), which call for universal access to electricity by 2030. Currently, more than 600 million people in sub-Saharan Africa (SSA) have no access to electricity, and the total installed generation capacity in the region is less than that of the United Kingdom. Thus, universal access in SSA is unlikely to be met under business-as-usual scenario, especially since the expansion of access to electrification has lagged behind population growth.

Based on relationships between electricity access on the one hand and GDP per capita, population density, and urbanization rate on the other, model projections show that following historical trends about 515 million people will still lack access to electricity in 2030. Eastern Africa is projected to have the highest proportion of people without access to electricity by that date (48 per cent), followed by southern Africa without the Republic of South Africa (44 per cent), western and central Africa (31 per cent), and the Republic of South Africa (12 per cent). Access to electricity is especially lagging in rural areas, which are projected to account for 85 per cent of the population without access by 2030.

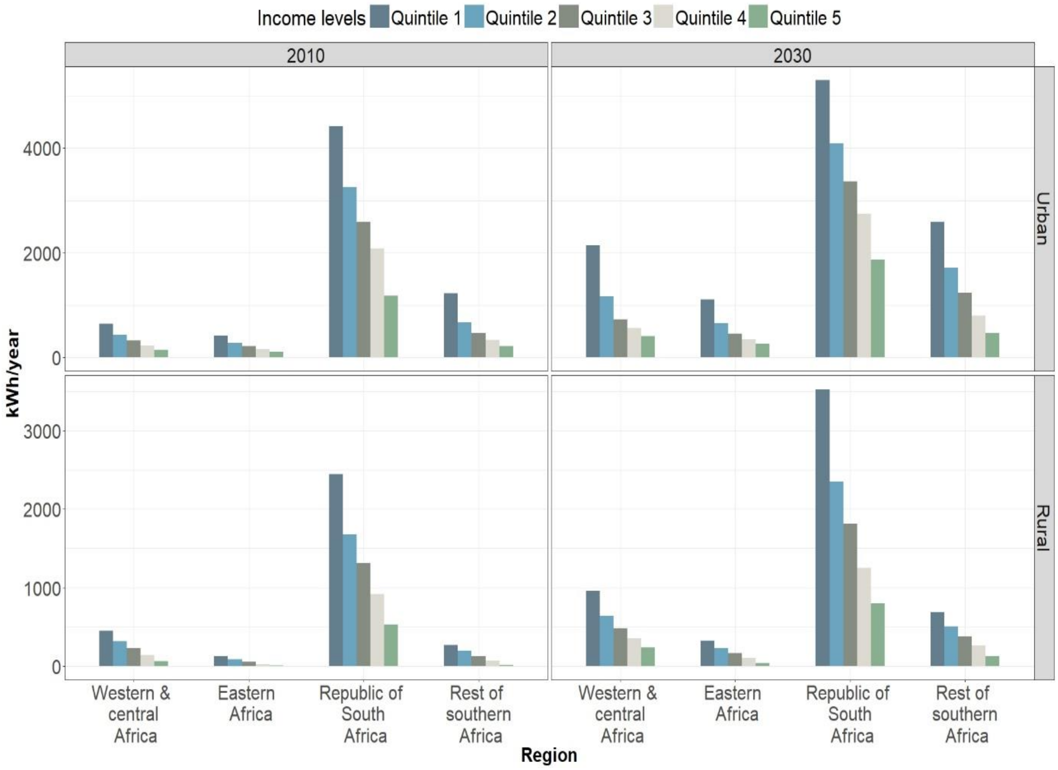
Providing universal electricity access requires major investments in generation capacity and transmission and distribution. However, strategies to achieve this goal should also consider possible trade-offs and synergies with other SDGs, including how they affect greenhouse gas emissions.

This article reports on a study that explored ways to achieve universal electricity access in SSA, technology options, investment needs, and synergies and trade-offs with global climate policy, using the integrated assessment model IMAGE-TIMER. The study sought to identify the roles of individual and institutional actors and the role of regulations in the transition to universal electricity access in SSA. It involved workshops conducted in the Netherlands and Ethiopia with actors involved in the region's electricity system; case studies of centralized and decentralized electrification programs and projects in Nigeria, Ghana, Tanzania, and Ethiopia; and a desk study.

The study applied three electricity-access scenarios: a baseline scenario which is a business-as-usual path where no measures are taken to increase or improve supply, a universal access scenario without a climate policy, and a universal access scenario with a climate mitigation policy in place in all regions. The scenarios were based on the exogenous assumptions and projections of the drivers of energy demand (e.g., population growth, economic development, rate of technology change, and urbanization rates) of the Shared Socioeconomic Pathways, as implemented in IMAGE. The model also uses data on cost of power generation by different technologies, population density, cost of transmission and distribution, technical potentials of renewable energy sources, and the distance of population settlements from an existing power line.

These findings are discussed in more detail in papers recently published in the journals *Energy* (Dagnachew et al., 2017, 'The role of decentralized systems in providing universal electricity access in Sub-Saharan Africa – A model-based approach', *Energy,* 139**,** 184–195); *Energy Policy* (Dagnachew et al., 2018, 'Trade-offs and synergies between universal electricity access and climate change mitigation in Sub-Saharan Africa'. *Energy Policy,* 114**,** 12), Dagnachew et al., Submitted, 'Actors and governance in the transition toward universal and sustainable electricity systems in Sub-Saharan Africa').

Regional differences in annual household electricity consumption, 2010 and 2030

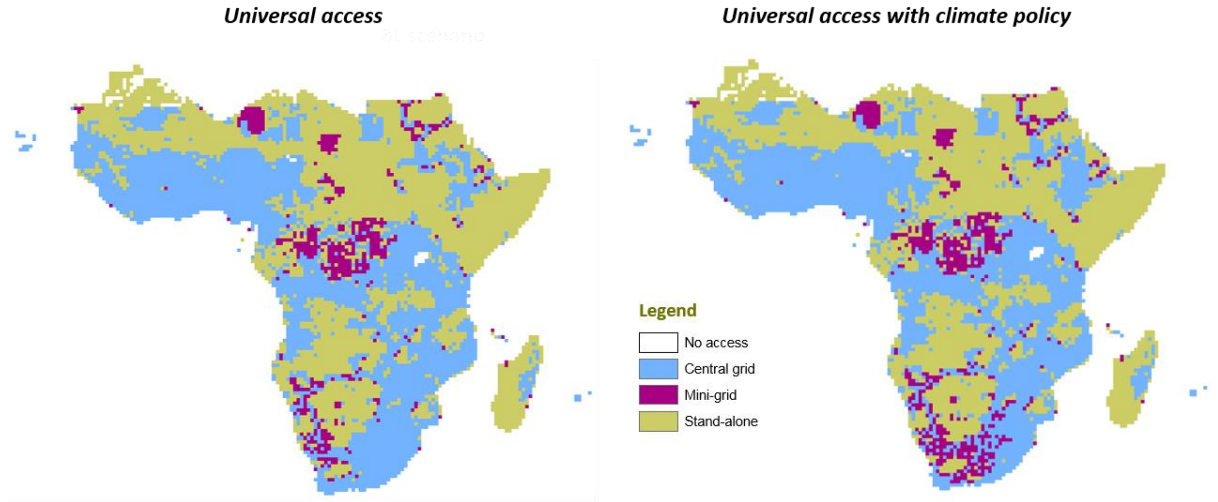


Pathways to universal electricity access

Currently, there are large differences in electricity consumption between regions, urban and rural areas, and income classes. While the average annual household electricity consumption in 2010 was under 350 kilowatt hours (kWh) in most of SSA, in the Republic of South Africa it was over 2300 kWh/year. There were also large differences between urban and rural areas and between income quintiles. These differences remain important in our projections. The projected annual growth in electricity consumption per household between 2010 and 2030 ranges from 2 per cent in the Republic of South Africa (as a result of the relatively high current levels and lower projected economic growth) to 6 per cent in eastern Africa.

Ways to provide access to electricity include grid, mini-grid, and off-grid systems. The preferred method largely depends on distance to an existing power line, population density, household electricity demand, and local resource potentials. For our default assumptions regarding electricity consumption, access to the central grid is the least-cost option to provide access for 85 per cent of the newly connected population in SSA, while over a 100 million people are projected to gain access through off-grid systems. However, if electricity demand remains low, it would be attractive to connect a much higher share of the population through off-grid systems. If governments target a minimum level of access in which households get enough power to light two bulbs and charge mobile phones, off-grid systems could provide access to more than 65

Least-cost electrification systems under the two universal-access scenarios



per cent of the newly connected population. Especially in poor, sparsely populated rural settlements in SSA, off-grid systems – including mini-grids and stand-alone systems – could play a vital role in providing electricity at a reasonable cost.

Achieving universal electricity access will require a significant further expansion of installed capacity as well as transmission and distribution infrastructure. The capital investment required is projected to exceed US$33 billion per year, between 2010 and 2030, on top of investments projected under the baseline scenario at US$16 billion. Of this investment, 85 per cent would go to upgrading and extending the transmission and distribution infrastructure, reflecting the severe lack of such networks and the inefficiency of the system.

Synergies and trade-offs with climate policy

Increasing energy efficiency is an important strategy for avoiding climate change by reducing consumption. If climate change mitigation policies are introduced globally, including in SSA, a 20 per cent saving in total residential consumption by 2030 might be achieved. This would mean that SSA would need 21 terawatt hours less capacity to serve the additional connections while providing the same level of energy services. Efficiency improvements, together with higher fossil fuel prices, would create more favourable conditions for renewable off-grid systems. As a result, under the universal-access scenarios, 10 million more people would be connected via off-grid systems in the scenario with climate policy than in the scenario without it.

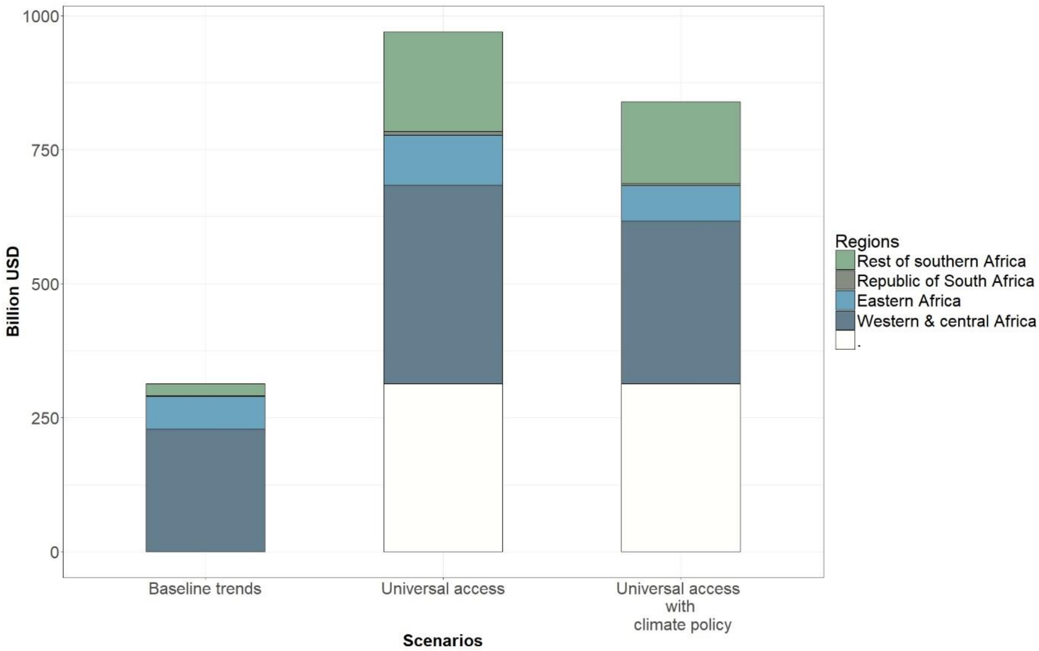
Climate policy will also make it cheaper to meet the universal electricity access target. The efficiency improvements will lead to lower additional investment requirements for generation capacity and transmission and distribution infrastructure for the additional connected population (US$27 billion a year, compared to US$33 billion a year without a climate policy). However, these capital investments do not cover the significant costs of implementing climate policy.

Stringent global climate policy also changes the electricity mix. While total electricity production from renewable energy sources does not change considerably in absolute terms, its share increases as the efficiency improvements lead to lower overall demand. Use of coal is projected to decrease especially significantly, while the share of natural gas for combined-cycle power plants will increase, as its carbon content is lower than coal's and it can be efficiently used to balance fluctuating renewable resources. The scenario also shows a significant increase in nuclear energy, especially in the Republic of South Africa.

In 2010, residential CO_2 emissions from electricity accounted for around 25 per cent of total electricity-related CO_2 emissions in SSA and only around 0.5 per cent of global electricity-related CO_2 emissions. Without climate policy, additional on-grid generation capacity mostly consists of scaling up existing capacity. Hence, achieving the universal access target will result in an increase in emissions of 24,000 tonnes of CO_2, which is three times those of 2010. Still, this increase can be considered negligible, as it is only around 0.2 per cent of the projected global electricity-related emissions in 2030. The shift to low-carbon energy sources and efficiency improvements due to carbon price will help avoid 65 per cent of the projected CO_2 emissions of 2030.

Climate mitigation policies are projected to result in higher electricity prices in all regions, with the price increase correlating with the share of fossil fuels in the mix. Eastern Africa will be the least affected as its electricity mix is dominated by renewable energy. Still, the price in this region is projected to be 25 per cent higher under the scenario with climate policy than under the scenario without it. In the Republic of South Africa, the model projects a 120 per cent increase in the electricity price due to the strong dominance of coal in the electricity mix.

Additional investments for universal electricity access compared to the baseline trend, 2010–2030



Governance for universal electricity access

Access challenges in SSA are not the result of lack of energy resources, as the region has ample fossil and renewable energy resources to meet demand. The challenges are rather a result of deeper governance and institutional problems as well as lack of capital to meet the high investment requirement.

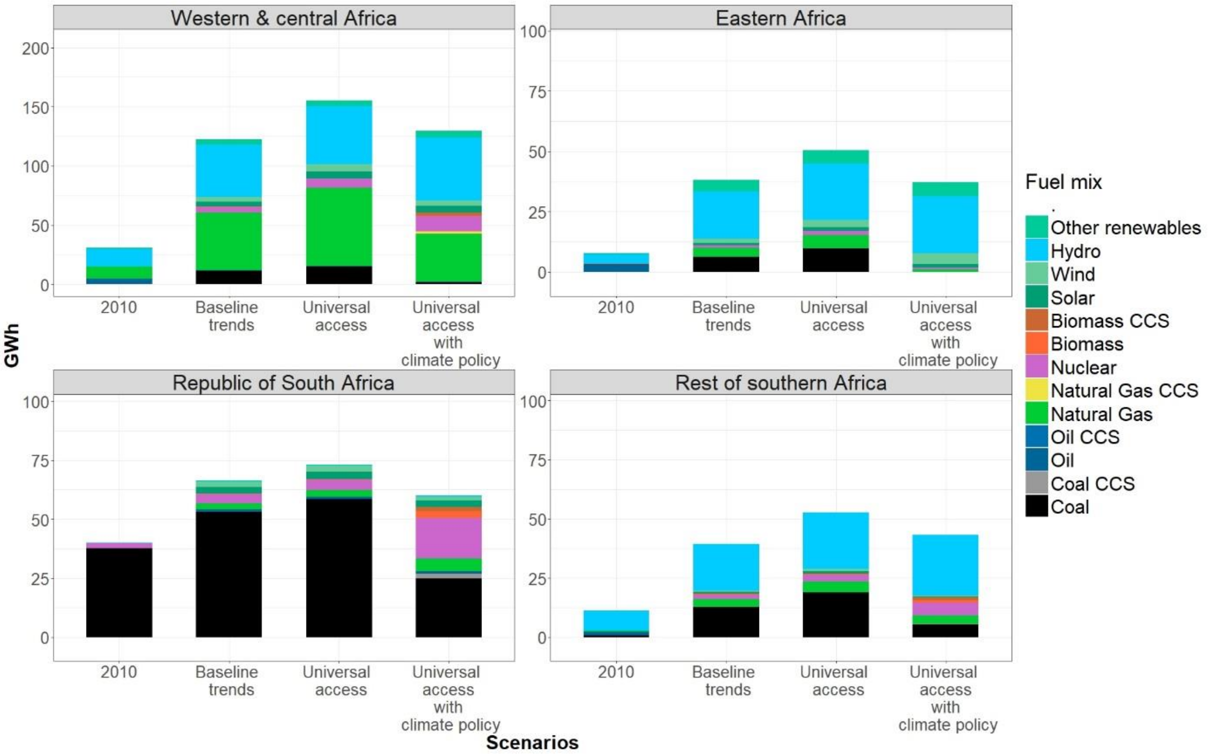
While the actors in the electricity sector and their roles differ by country and by project, governments generally have a strong presence in electrification. In several countries, a single public utility with a top-down governance structure has been the main or only actor in electrification for a long time. Of the countries we studied, Nigeria is the only one where power generation within the central grid is privatized. Power distribution in Nigeria is also fully privatized, while Ghana's Enclave Power Company is a private-sector entity involved in the country's central grid system. In Ethiopia and Tanzania, all components of the central grid are owned and operated by the government.

The current governance structure is associated with corruption and inefficient management of several utilities over long periods of time. As a result, the energy system functions poorly with an unstable and unreliable electricity supply, low generation capacity, low efficiency, inadequate investment, high costs, and prices that have often been too low to cover costs. Other problems in the sector include lack of human resource capacity, power theft, lack of stakeholder collaboration, lack of consumer awareness on energy efficiency, and poor quality products. These have resulted in a sector-wide revenue gap, increasing the risk for private-sector participation.

The private sector is gradually growing in the off-grid electricity market, but institutional and financial capacity problems persist in many of these countries. The number of household and community energy producers (and consumers) is growing, while rural electrification agencies are being established with the mandate to facilitate rapid electrification, engaging producer-consumers and the private sector. National electricity policies are designed with the SDGs as the central element but require better institutional arrangements and human capacity, and greater collaboration between different actors. While community engagement and empowerment are crucial for wider deployment and sustainability of off-grid electrification systems, there has been very little community participation in the design and development of electrification programs. Institutional barriers (most of all corruption), weak stakeholder collaboration, lack of finance, and high transaction costs are among the obstacles mentioned repeatedly by study participants to expansion of decentralized systems. Problems also arise from the lack of communication between the public and private sectors.

Several countries have developed regulatory instruments to facilitate the penetration of decentralized systems, including financial incentives (e.g. start-

Fuel mix for residential electricity generation



up grants and loan guarantees), fiscal incentives (e.g. exemptions from import duty and/or value added tax), and elimination of market distortions (e.g. reducing fossil fuel subsidies). Capital subsidy is one of the most widely adopted policy instruments to help off-grid projects overcome the initial investment barrier. The Ethiopian government has provided duty exemptions for solar power equipment, and the governments of Ghana, Nigeria, and Tanzania have subsidized the cost of the photovoltaic module.

Tanzania, Ghana, and Ethiopia have set up special funds to broaden financing channels for off-grid projects. Crowdfunding, for example through TRINE (www.jointrine.com), has financed solar projects in Tanzania and Uganda. Operating and maintenance subsidies are seen as essential to sustain project operations over a long period, particularly in the case of extremely remote areas with a poor ability to pay. Microfinance has enabled rural households to set up solar home systems in Ethiopia.

Conclusion

To achieve universal electricity access, on-grid systems will need to be complemented with off-grid technologies. Between now and 2030, policies will need to ensure access to electricity for over 500 million new customers. While on-grid electricity would be cost-effective in most cases, renewable mini-grid technologies could provide electricity access to over 180 million people depending on the targeted level of consumption. Decentralized renewable-energy-based systems, largely based on solar photovoltaic technology, can be implemented with relatively low initial investment, gradually scaling up capacity as the level of consumption increases. However, in large parts of western and southern Africa, due to their high population density and relatively high household electricity consumption, the central grid remains the preferred electrification option.

International climate policy could make universal access to electricity cheaper. Universal access is projected to require annual investments of US$27 billion with climate policy and US$33 billion without one. Carbon pricing lowers the required investments through efficiency improvements in household appliances and learning in renewable energy technologies. While this increases electricity prices, it could also be considered an opportunity to move away from fossil fuels and improve energy security.

To facilitate universal electricity access, institutions in the electricity sector need to stimulate innovation in supply technology and business models by establishing a functioning electricity market. The institutions in SSA are generally weak and unable to cope with population growth and technology developments. Especially for off-grid systems, stable and consistent policy frameworks, clear technical standards, and certification for new technologies are crucial. They also require innovative revenue schemes and differentiated financing schemes (e.g. low-interest loans, public–private partnerships, and carbon finance). Similarly, governments could work to lower the transaction costs for decentralized systems through appropriate policies and capacity-building programs.

SUSTAINABLE ELECTRIFICATION IN AFRICA

Gregor Schwerhoff

What is the objective of electrification in Africa? The Sustainable Development Goals (SDGs) provide a list of societal objectives for evaluating policy.

Electrification is expected to contribute to ending poverty (Goal 1), ensuring quality education (Goal 4), ensuring access to energy (Goal 7), promoting economic growth (Goal 8), and other

Many of these emerging issues relate to the fact that the current wholesale market was designed before decarbonization, when it handled a very different supply mix. The limitations of the existing market design were recognized by the Market Design Committee that originally developed the system. It was intended as a temporary solution that would transition to a system with locationally-varying pricing over 18 months, but it has remained in place for one and a half decades.

Various patches and temporary improvements have been layered onto the original design, but these are insufficient to address today's challenges. The inefficiencies of the existing design have been documented and analysed by the IESO, the market monitor, and independent observers. The changing supply mix and increasing flexibility needs have amplified these challenges. The introduction of new technologies, such goals. All these goals are promoted directly through the availability of electricity and explain why electrification is so high on the policy agenda. However, there are trade-offs, and progress towards one of the SDGs can have positive or negative effects on progress towards others. If electrification is to improve human well-being, it needs to be sustainable – that is, it needs to ensure healthy lives (Goal 3), combat climate change (Goal 13), and protect ecosystems (Goal 15).

Making electrification sustainable requires identification of suitable energy sources. Electricity generation in Africa has been dominated by coal and gas; in 2015, only 0.33 per cent was sourced from solar power and 0.96 per cent from wind power. This, however, appears poised to change. The figure below shows which technologies are projected for Africa based on analysis using integrated assessment models. These results were obtained in a model comparison study as optimal ways to limit climate warming to no more than 2°C. The technologies include biomass, the combination of coal with carbon capture and storage, and nuclear power. It may not be possible, however, to use large amounts of biomass within planetary boundaries. The use of coal, even when combined with carbon capture and storage, still causes local air pollution, which is harmful for health. Nuclear power may be more expensive than previously thought. These three technologies are thus suitable for mitigating climate change but have negative effects on other aspects of sustainability.

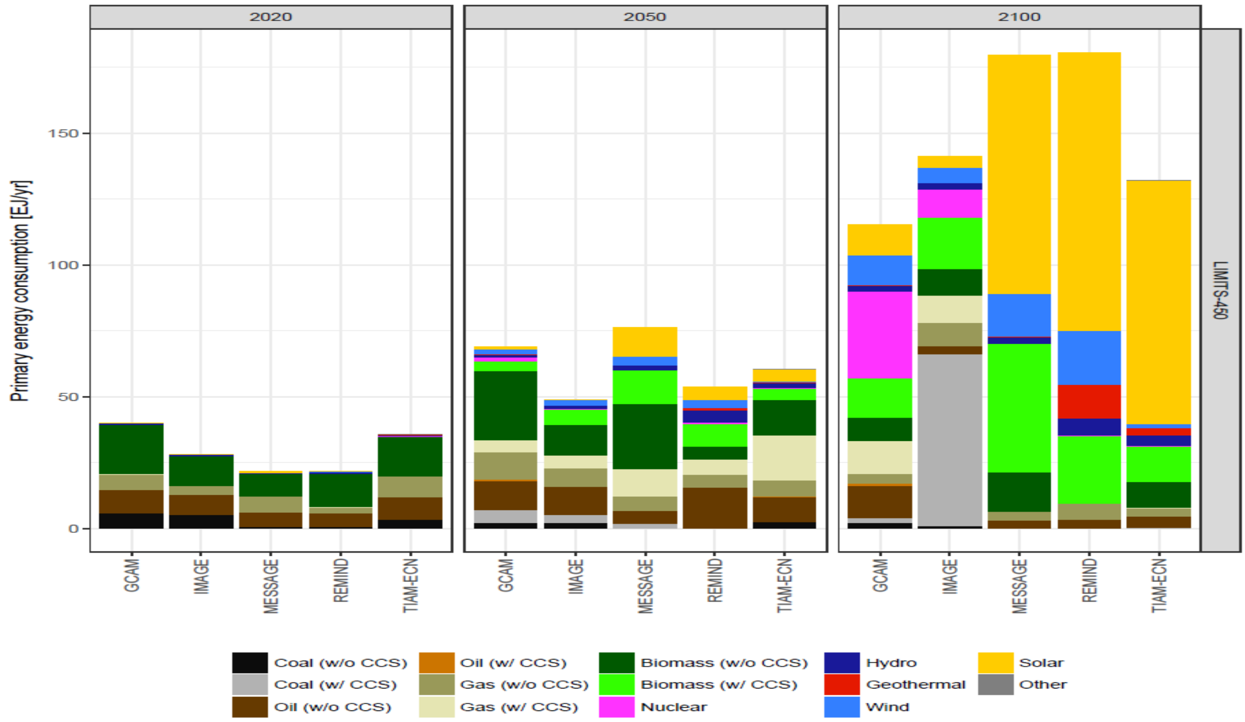
To identify a sustainable approach to electrification for Africa, recent studies have examined the possibility of using mostly variable renewable energy (VRE). While prices for VRE are falling continuously and have reached the cost of fossil fuels in Africa, management of variability has been considered a major obstacle to large-scale deployment. To address this challenge, some studies have introduced detailed representations of technologies for managing variability into integrated assessment models and have shown that very high rates of VRE can be achieved and would allow for rapid economic development. Others identify leapfrogging opportunities for the African energy system, with some arguing that renewable energy can eventually provide 100 per cent of Africa's electricity (see here). In contrast to other energy sources, renewable energy offers the opportunity to make progress on development without moving backwards on health and sustainability.

Schwerhoff and Sy (2018;) analysed the energy mix in Africa in detail; this article focuses on the consequences for the electricity grid infrastructure of using renewable energy.

Decentralized electricity grids and renewable energy

Decentralized energy generation reduces the pressure to extend the electricity grid to remote locations. This is especially important for sub-Saharan Africa, since many households live in areas that would be disproportionately expensive to connect to the national grid in the short term. For very isolated households, solar home systems are the most economical way to provide basic energy access. They bring substantial welfare benefits and significantly reduce energy expenditure. These savings mean that the system is amortized long before its lifetime ends. In addition, the price for solar home systems is falling substantially while the quality keeps improving. Solar home systems also provide health and safety benefits.

Projected Energy mix in Africa, 2020–2100



Source: Author's calculations using data from the LIMITS Scenario Database. Schwerhoff and Sy (2018) (Developing Africa's Energy Mix. Climate Policy, 1–17; CCS = carbon capture and storage.

Solar home systems generally have lower capacity than grid power, however, and some studies have concluded that they cannot provide a full substitute for grid power. In this context it is important to keep in mind that there are different levels of energy access. The Secretary-General's advisory group on energy and climate change (AGECC (2010) has distinguished between 'basic human needs' (level 1), 'productive uses' (level 2), and 'modern society needs' (level 3). Some small systems provide only level 1 energy access. In addition, solar home systems still need to be subsidized, since many households face strong credit constraints. Despite these limitations, solar home systems offer an important option for electrification in remote areas.

For villages with more than 500 densely grouped households using three to four low-power appliances each, micro-grids are the best option. The figure below illustrates what a mix of national grid, micro-grid, and solar home systems could look like in Nigeria: transmission lines through the most populated areas connect strategically located power plants throughout the country, electrifying the surrounding area. Beyond a certain distance from the lines, either micro-grids or home systems are used, depending on population density.

For several years now, mini-grids based on renewable energy have been a lower-cost option for many communities than grid connection or mini-grids based on diesel. Zeyringer et al. (2015) (Analyzing Grid Extension and Stand-Alone Photovoltaic Systems for the Cost-Effective Electrification of Kenya." *Energy for Sustainable Development* 25 (April): 75–86) projected that off-grid photovoltaic (PV) systems could reach 17 per cent of the population cost-effectively by 2020 in Kenya. In addition, some studies show that local generation of renewable energy can lower the cost of electricity supply to grid-connected villages, mostly by reducing grid losses, and increase the quality of supply.

The rapid spread of small electricity grids is powerfully driven by mobile phones and the virtual financial services that come with them. Mini-grids are preferred to solar home systems due to the better services they offer. When the national electricity grid is not fully reliable, PV-based communal grids may even be preferred to the national grid. While electrification increases electricity consumption, it has the potential to reduce greenhouse gas emissions, since it reduces the demand for pollution-intensive energy forms.

Renewable energy and the design of the electricity grid

While decentralized electricity supply is an attractive option for remote areas, the majority of households can be reached most efficiently through the national electricity grid. The following sections discuss future electrification trends in Africa and ways to adapt to the variability that accompanies use of VRE.

The future of electrification in Africa

As recently as 2013, integrated assessment models projected that solar and wind power would have only a limited role in the electricity supply of Africa, even in scenarios with a climate policy. This changed when some rather coarse ways of representing the challenges of integrating VRE, like firm upper bounds on VRE penetration and other simple approaches to representing flexibility requirements, were addressed explicitly. These coarse methods had been adopted to compensate for the lack of representation of temporal and spatial variability as well as integration options like storage or pooling through grid expansion in the model setup. When integration options were modelled accurately, it became clear that high shares of VRE are realistic.

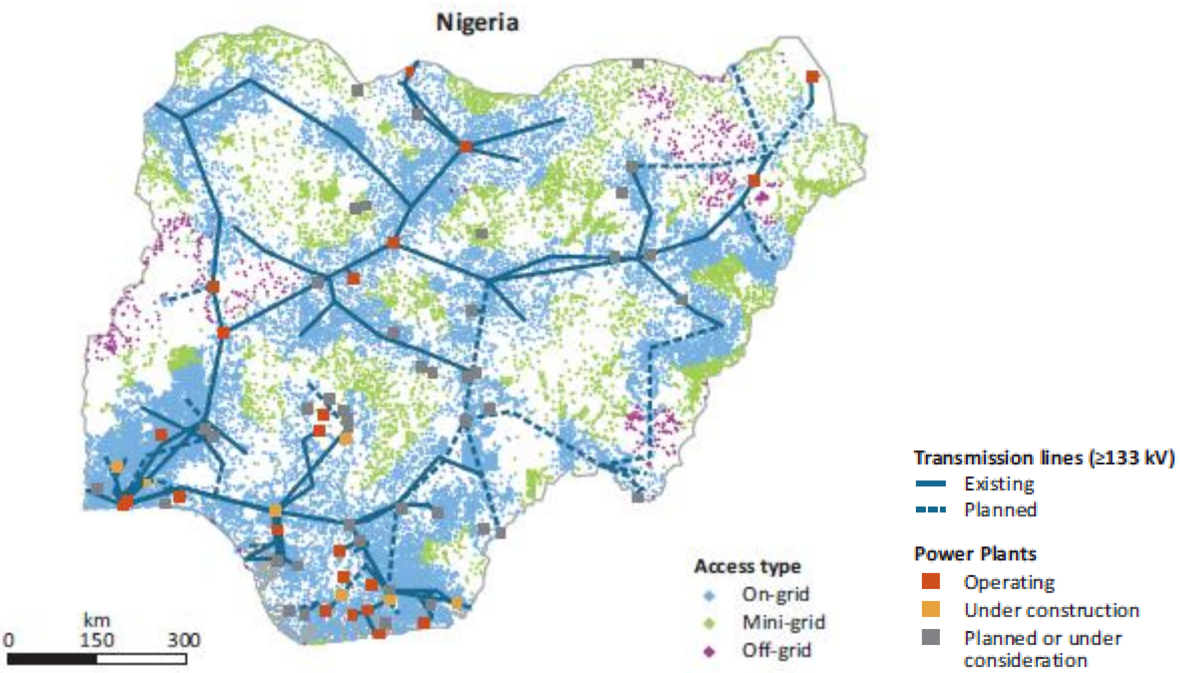
Solar energy as a large-scale power source for the electricity grid has been systematically underestimated for a long time. In addition to the insufficient representation of VRE in models, technological learning on solar energy was underestimated. A range of integration options for VRE can make solar energy an important part of the electricity supply in Africa. These options will have to be used in order to realize the potential of solar energy. If this is done, Africa can remain below average in per capita emissions even when GDP catches up with the most developed regions, as is assumed will occur in the course of the century.

Some studies have demonstrated the potential of short-term storage (for example, flow batteries) and hydrogen electrolysis for balancing out diurnal and seasonal variation. Integrating these solutions would make an energy mix with nearly 100 per cent renewables optimal for Africa from 2040 onwards. Others have pointed out the role of the different types of solar energy. At low penetration rates, PV is the least-cost option. As variability becomes more important, concentrated solar power systems can be constructed, as this technology is less variable than PV.

Adapting energy infrastructure to accommodate variable renewable energy

Among the options for preparing energy infrastructure for VRE, the expansion of the electricity grid receives the most attention. Low connectivity is among the challenges for the electricity system in sub-Saharan Africa. Interconnections built for the best available renewable options will look different from those built for traditional networks (based mainly on hydropower, for example). As many of the connections built for an optimal use of energy will require

Optimal mix of grid types in Nigeria, based on anticipated expansion of the main transmission lines



Source: IEA 2014, Africa Energy Outlook: A Focus on Energy Prospects in Sub-Saharan Africa (Paris: International Energy Agency).

international or regional cooperation, Oseni and Pollitt (2016) ("The Promotion of Regional Integration of Electricity Markets: Lessons for Developing Countries." *Energy Policy* 88 (January): 628–38; have made detailed recommendations for promoting the regional integration of electricity markets. Given significant gains of trade for electricity and examples of cooperation between countries with a history of conflict, they argued that there is reason to be optimistic that this can successful. Nevertheless, there are substantial political and practical barriers to international integration.

Some studies have explored the potential of regional integration for managing variability in specific subregions of Africa. Studies on the use of renewable energy in North Africa consistently find that market integration and cross-border power exchanges have the potential to significantly improve efficiency. South Africa has more powerful wind energy resources and Tanzania has more reliable ones. This provides a classic opportunity to benefit from trade, given that the countries are well connected. The harmonized positioning of renewable power plants and interconnections in southern Africa can reduce the need for capacity and result in sizeable cost savings.

Improving interconnections is not the only way to adapt energy infrastructure to renewable energy. An important option is to use hydro dams as virtual batteries for solar PV and wind energy. This solution is of particular importance in Africa, since the continent is well endowed with hydropower. While hydropower is used well for the moment, VRE can be a good complement to hydropower in case climate change makes the latter less reliable.

A further option for adapting to variability is the integration of the electricity system with facilities for desalination and gas-to-power transformation. Finally, grids can be built as smart grids. This would allow the dynamic balancing of electricity generation and demand. As a result, Africa could leapfrog some aspects of traditional power systems and accelerate its electrification.

Conclusion

Given the advantages of renewable energy, it may be taken for granted that electrification in Africa will be sustainable. Unfortunately, however, current choices indicate that it will be a challenge for Africa to avoid a carbon lock-in. Coal is experiencing a renaissance in developing economies. Egypt, with 15 gigawatts (GW) in active development, and South Africa (12 GW) are among the top countries for new coal power development, with Zimbabwe, Malawi, and others also building considerable coal capacity. In this context, it is important to note that this article is concerned with technical and economic issues. There are barriers in terms of political economy as well as historic and institutional reasons for the choice of conventional power plants and coal in particular. An important example is the bias of financing institutions from outside Africa towards conventional plants.

At the same time, renewable energy is breaking through in Africa. According to data from the International Renewable Energy Agency, both wind and solar energy have shown very strong growth in recent years, each growing at least 15 per cent per year. According to Ueckerdt et al. (2017, Fig. 10) ("Decarbonizing Global Power Supply under Region-Specific Consideration of Challenges and Options of Integrating Variable Renewables in the REMIND Model." *Energy Economics* 64: 665–84. Africa could be the first region to decarbonize almost completely; this could occur by the year 2050. Van Der Zwaan et al. (2018) ("An Integrated Assessment of Pathways for Low-Carbon Development in Africa." *Energy Policy* 117: 387–95, found evidence that Africa has the opportunity to leapfrog fossil fuels and directly fulfil its energy requirements with renewable energy. There are also indications that the political reasons for favouring conventional power are weakening, as coal power plants in particular are at risk of becoming stranded assets.

Electrification infrastructure will play a decisive role in overcoming the challenges and grasping the opportunities described in this article. Concerning the choice between on-grid and off-grid electrification, the opportunities offered by decentralized renewable energy should be fully exploited and considered in decisions on grid extensions. As a second step, investment in energy infrastructure should be harmonized with up-to-date knowledge on the best available energy mix for Africa. This will likely include more investment in connectivity, the use of existing and new storage capacity, and smart grids.

ELECTRIFICATION PLANNING WITH A FOCUS ON HUMAN FACTORS

Roxanne Rahnama and Ignacio Pérez-Arriaga

Despite the steady improvement in electrification rates in low income and developing countries (LIDCs) in the last few decades, an estimated 16 per cent of the global population – over one thousand million people, largely concentrated in India and sub-Saharan Africa – still lack access. Progress toward the Sustainable Development Goal of universal access by 2030 remains elusive in sub-Saharan Africa, where population growth matches the electrification rate. Even these statistics are gross underestimates of the true magnitude of access challenges, given the inconsistencies in how electrification is measured by various governments, as well as the financial and psychological costs imposed on the millions more living with unreliable power.

The stubbornness of the problem has financial, technological, and social roots. Populist policies directed at meeting residential and agricultural demands have kept electricity tariffs below supply costs in practically all sub-Saharan countries, rendering the distribution utilities bankrupt and thus unable to invest to connect more customers, which would further exacerbate their financial situation. The traditional approach to electrification by grid extension becomes impossibly expensive for the small and dispersed demand in rural areas. Frustrated customers with unreliable service stop paying their bills or decide to connect illegally, developing an adversarial relationship with the distribution company. Governments periodically must bail out these companies at a high cost, because of their enormous losses, leaving the root cause of the problem untouched. Other dimensions of the problem, in particular the lack of investment in generation and transmission infrastructure, are beyond the scope of this paper.

Only recently, developments in photovoltaic generation, battery, and information and communication technologies have offered the possibility of off-grid electrification in rural areas. These off-grid supply technologies further serve as complements or alternatives to unreliable supply anywhere. Although off-grid solutions are cost competitive with grid extension for small and dispersed loads, they may not be affordable for many potential users, and may not be suitable for electricity-intensive appliances and community and productive uses.

Too often, electrification planning is exclusively addressed from techno economic perspectives, without seriously questioning the nuanced ways in which electricity services are actually perceived, used, and paid for at various levels. Here we argue that no solution will be satisfactory unless it addresses the complex socio-political, cultural, and behavioural factors that contribute to the present unsatisfactory situation of electricity access in LIDCs.

The complexity of electricity consumers has often been neglected in the discourse on financially sustainable electrification. Recent experiences and studies have revealed widespread variability in the attitudes, behaviour, and decision-making processes of the energy poor – which is manifested in consumers' valuation of different electricity attributes, their aspirations for access and reliability, and their opportunities for future productive growth. Differences in the political, informational, and technological environment for consumers in low-access countries create non-negligible effects on their psyches and subsequent valuations of different electricity attributes. To serve these populations well requires consumer-centred business models.

Utility metrics

In this section we define and examine in detail the key metrics that are used in electrification planning to characterize energy poverty, welfare, reliability, and access levels. We focus on willingness to pay, ability to pay, and the cost of non-served energy, examining their relationships with quality of service.

The ultimate goal of electrification planning is to maximize the social welfare associated with electricity supply. Assuming that the price of electricity is known, its affordability (and that of electrical appliances) for the customers and their preferences will determine their optimal level of consumption and the associated *utility function* of electricity utilization for each customer, which equals his or her willingness to pay (WTP) for the service.

WTP is constrained by ability to pay (ATP). WTP reflects not what customers would pay if they could, but what they are willing to pay out of their actual resources. It cannot exceed ATP, and it may not be realized in practice if there is insufficient access. The perfect access level can be defined as the one that does not limit the supply of electricity that customers are willing to use and to pay for, as described by their WTP, adjusted for any existing subsidies.

The WTP of any customer for the first few watt hours of consumption is very high (if you do not believe this, check the first lesson in any microeconomics textbook on the price/demand curve). This is why many poor customers in LIDCs pay, in monthly or weekly fixed amounts, an extremely high price – when calculated in per unit of electricity consumption – for the small amounts of electricity that they consume in on- and off-grid systems. When the ATP increases, the total amount of electricity consumed increases and (again the price/demand curve) the marginal WTP decreases. Efficient tariffs are based on this marginal WTP, resulting in consumer surplus, since the consumers are willing to pay more than this marginal WTP for the first units of energy. If tariffs are not regulated, the poorest customers may end up paying a high price, close to their marginal WTP, with a very low surplus.

Failures of electricity supply reduce the continuity and quality of the electricity received by customers, and consequently their utility functions or

WTP. The corresponding loss of utility to each customer is also termed the cost of non-served energy (CNSE).

The term 'reliability' broadly describes how well the power system does in supplying electricity – the quality of service. It encompasses the continuity of the service, which in turn is described by the frequency, duration, and quantity of demand affected by an interruption, as well as the time at which the interruption occurs. Reliability also includes the technical quality of the supply: the voltage level, waveform shape (if in alternating current), and micro-interruptions. Studies of consumers' responses in LIDCs have concluded that WTP critically depends on reliability, with its many attributes.

In industrialized countries, most customers are accustomed to almost perfect reliability and almost never have to make choices in this respect. The situation in LIDCs is very different: both planners and customers face trade-offs between cost and reliability. Nonsophisticated customers have to choose among several delivery modes and options within each mode, each of which comes with varying costs and levels of reliability. It seems that we have not yet been able to figure out a fully satisfactory approach to incorporating reliability performance metrics into human-centred business model planning in LIDCs.

The term 'willingness to pay' (WTP) suggests a method of measuring or estimating the value of individual utilities, just by asking customers how much they would be willing to pay for a supply of electricity with certain characteristics. However, this is more simply said than done. Just think what you would pay to have one unit of electricity at different times of the day and under different circumstances (e.g. while sleeping, in an elevator, or charging your phone). In practice it is somewhat simpler to ask for the CNSE – how much a customer would pay to avoid an interruption of electricity of a specific duration at a given time. However, again, in the context of electricity supply in LIDCs, it is more useful in the interaction with customers to use, for instance, the WTP per month for an electricity supply of some characteristics. Current methods for estimating these WTP values include contingent valuation and discrete choice experiments that aim to model either directly stated or indirectly revealed preferences.

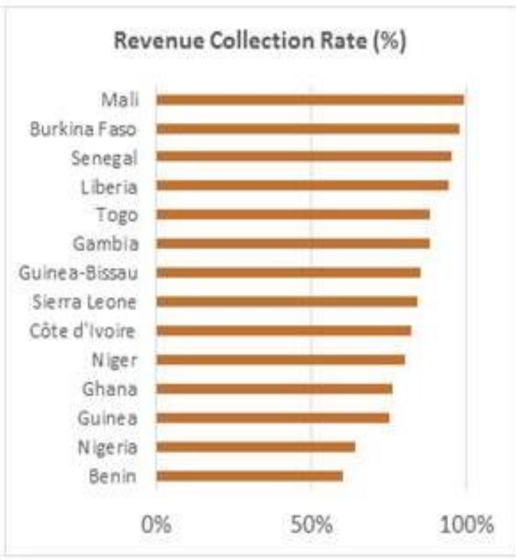
Electrification planners who use computer models need to represent the cost of lost supply in their simulations. In this context, it is useful to assign a CNSE value to every kWh that is curtailed in the power system. If the model is able to work at the individual customer level, as is the case for the Reference Electrification Model REM (see http://universalaccess.mit.edu), it may be possible to distinguish between a CNSE for critical loads at certain times of the day and another, lower CNSE for the rest of the demand. But it remains difficult to estimate the value of CNSE. A simple way to circumvent this problem is to use the computer model to obtain the electrification plan several times, each time with a different CNSE value, and let the customers (or the system planner with input from the customers) decide which plan, with its combination of cost and performance, is preferred.

One more nuance regarding CNSE relates to the context in which electrification planning takes place. In a multisectorial planning context, the planner may have to, for example, assign limited resources to health, education, transportation, and electrification objectives. In this case, the CNSE refers to the difference between having some level of electricity access and having none at all. This can make a major difference in the wellbeing of a household or community. On the other hand, in the context of electrification planning alone, everybody is supposed to receive some kind of electricity supply, and the meaning of CNSE is the one described before: the cost to the customer of an interruption to existing supply levels.

Understanding income-constrained consumers

As indicated above, the relationship between electricity users and suppliers is generally much more complex in LIDCs than in industrialized countries. Commercial losses – resulting from unpaid bills and illegal connections – are very high, as shown in the following sample of revenue collection rates in western Africa. Off-grid options for many of these existing or potential customers complicate the picture even more.

The success of an electrification plan under these complex conditions critically depends on a well-thought-out consumer engagement plan, and on understanding what the customer wants. The utility derived from



electricity use has two main components: the 'utilitarian' attributes that are directly associated with its instrumental and functional purposes, and the more subjective 'hedonic' attributes such as pleasure, happiness, and social stature that it provides. When consumers choose between various options, the ways in which they assess the trade-offs are influenced by social, economic, demographic, behavioural, and technical components that interact with each other. The continuity of power supply and other measures of quality of service – like voltage level or customer interaction – have a major impact on consumers' valuation of the utilitarian attributes for both grid and off-grid services. There are also large differences in the social and hedonic attributes. For example, while the actual utilitarian or functional attribute of reliable electricity from a microgrid or solar home system may be much higher than that of unreliable grid access, the perceived hedonic attributes of grid electricity, such as higher social status associated with connection to the grid system, may hold greater weight.

Socioeconomic and demographic factors such as higher income, educational status, number of school-age children, and ownership of or aspiration to own a home business generally indicate an increase in the perceived utility or WTP. In contrast, studies have found age, occupation, and household structures to have more ambiguous effects. WTP depends on how reliability is measured or presented to consumers. For example, household WTP differs according to whether the expectation of an outage is communicated beforehand. WTP also depends on differences in households' financial ability to cope with outages by using alternative backup sources (e.g. diesel or kerosene) or simultaneous grid and off-grid connections.

Behaviourally, different cognitive factors – including negative reciprocity, trust, reference dependence, status quo bias, mental accounting, and information and inattention bias – can theoretically influence consumers' WTP; often, the direction of the effect varies based on the aforementioned demographic, socioeconomic, and technical parameters. For example, the age or educational status of a household member has important implications for the degree of reference dependence, status quo bias, and inattention bias held and the ways in which this affects WTP. The ways in which information is communicated to consumers can also have profound effects on trust and the propensity to hold a bias of negative and/or positive reciprocity toward the government or a private electricity service provider.

Implications for customer-focused electrification approaches

Several successful experiences with distribution franchises, mostly in India, have shown that a prerequisite for any kind of consumer engagement activity is an electricity supply with an acceptable technical quality of service. However, diverse complementary measures are also necessary to promote sustainable, long-term shifts in consumers' attitudes and behaviour. We have grouped them into three categories.

- **Electricity theft, attitudes toward tariff hikes, and bill payments:** Where trust and reciprocity are low – with outbreaks of hostility when utility employees attempt to enforce bill payment – strategies based on the threat of pecuniary penalties or social shaming may backfire. Receptivity to messages can depend heavily on the person or entity communicating the message: a threat or shame-based nudge may carry much more weight when it is communicated by a trusted local leader rather than by a service provider who is perceived as illegitimate or untrustworthy. Some degree of experimental testing should be carried out by the electricity provider, in partnership with a local community network, to identify the social signalling design that would work most effectively and sustainably under local social and cultural norms.

- **ATP-related challenges:** Sensitivity to local cultural and social norms is also necessary in relation to ATP. It has been found that a financial incentive scheme that involved monetary awards for energy conservation and penalties for poor conservation practices rebounded, likely due to low-income consumers' mistrust of particular financial contracts. Default (opt-in/opt-out) schemes for saving money may have lower levels of acceptance than individual or pooled savings mechanisms administered by locally trusted savings and credit groups that partner with the electricity service provider. The efficacy of some personalized messaging tactics may be contingent on the prevalence of mobile applications and mobile payment adoption in a particular country or region. Thus, sensitivity to both technological and cultural constraints should be maintained when designing interventions to enhance ATP.

- **Closing the gap between appliance ownership and aspirations:** When planning interventions to help consumers acquire the appliances they aspire to own, it is important for electricity service providers to take into account phenomena that may vary with local economic and social conditions. For example, an opt-in/opt-out 'appliance savings account' may be effective where a service provider is well trusted and has a strong relationship with consumers. But it may fail in the absence of ground-level capacity and long-term trust-building; in environments with high information asymmetries and poor communication about expectations, consumers will likely perceive it as a scam allowing the service provider to steal their money. An initial analysis of attitudes toward government vs. private electricity service provision and randomized testing of different promotional tactics is important for creating approaches that will be effective in a specific country and context.

Conclusion

There is enough evidence to support the idea that a better understanding of customers and a focus on customer engagement is essential for the success of electrification processes in LIDCs.

ACCESS TO SUSTAINABLE ELECTRICITY IN MALI

Maryse Labriet

In 2016, roughly 1 billion people or about 13 per cent of the world's population lived without access to electricity, according to the 2018 Energy Progress Report of the World Bank. In Mali, a landlocked country in West Africa, 12 million people or 65 per cent of the population lacks access to electricity, according to national household surveys; in rural areas that proportion rises to 75 per cent.

This situation is unacceptable. Sustainable electricity access is part of the United Nations Sustainable Development Goals, adopted in 2015, and is widely acknowledged as a critical enabler of development, not only by increasing income possibilities (productive uses) but also by improving health, education, and general quality of life (community and household uses).

Off-grid renewable electricity is part of the solution. Compatible with low-carbon transitions and reduced climate vulnerability, off-grid renewable electricity is also better adapted to the characteristics of remote communities than grid-connected solutions. How can we provide sustainable electricity access to all? What do stakeholders think? While there is no simple solution to this challenge, a number of recent developments provide food for thought.

Access: definitions, models, and data

The definition of electricity access is important, because it drives objectives, models, and monitoring of progress. Most statistical measures have defined access as connection to the national grid. This definition is simple and easy to measure, and statistics are usually available from the energy utilities. However, it does not capture electricity access through off-grid options, which are rapidly increasing. It also ignores the quality of the connection; for example, outages and breakdowns, quite frequent in Mali, affect commercial, industrial, and social activities. And it does not consider the real consumption of electricity: a household that is connected to the grid may not able to afford to use much electricity or may not have access to appliances.

The multi-tier framework proposed by the World Bank, encompassing several levels and both quantitative and qualitative dimensions of electricity access, is a good move forward. It also means a new approach to data, since data on energy access at national levels are usually limited to connections and does not provide a complete view of the situation.

For example, in Mali, the formal grid connection rate was estimated by the utility Energie du Mali (EDM) at 27 per cent in 2016, while household surveys reported a 35 per cent electrification rate. Several reasons for this difference are possible, including assumptions about household size; informal connections to the grid; and off-grid supply from diesel, solar, and hybrid mini-grids and from stand-alone solar home systems, the market for which is growing quickly and could become visible in statistics in the near future.

From top-down to bottom-up electricity planning

In the link between electricity and development, what counts most is not electricity itself but the value of the services provided by electricity access, such as heat for cooking; lighting; refrigeration of food or medicine; mechanical force for water pumping, cereal grinding, and other industrial activities; and operation of communication and entertainment devices.

The focus on energy services constitutes a radical change in the way of looking at the energy system. The usual supply-driven electricity planning must be replaced by demand-driven planning. This requires moving from a top-down to a bottom-up decision framework. Moreover, given the magnitude of the needs and the differences in the characteristics of the different electricity services, priorities must be well established and a progressive plan must be implemented to reach universal access in stages.

Should households be given priority? community services? productive uses? Should a minimum access level for welfare be mandatory, and if yes, what should that level be? There is no good or bad answer and no easy solution;

each country must define its own targets and deadlines on the path to universal access. When asked "What are the most urgent energy services to be satisfied in Mali?" in an informal consultation in 2015, stakeholders selected energy services for healthcare and for clean water access. The same priorities were expressed in another project in Togo in 2013–2014. In Mali in 2015, 88 per cent of the primary schools and 11 per cent of the secondary schools had no access to electricity. Why not establish the target of providing electricity services to all health centres or all schools in five years?

New forms of governance

A multisectoral and multistakeholder task force can be a powerful tool to bridge stakeholders' varied goals and interests. Decision-makers and experts from outside the energy sector – for example, from the health, education, development, and environment sectors – must be involved in order to generate at least a real dialogue, at best cross-cutting decisions. National Multisectoral Energy Committees have been established in some African countries.

This type of governance is sometimes challenging due to competing views, priorities, and funding; but experience, as in the recent EERA project, has shown that it also allows existing resentments and preconceptions to emerge and be openly discussed, and expands awareness of the expertise available within the countries. The committee in Mali explored synergies between existing plans such as the National Action Plan on Renewable Energy, the National Action Plan on Energy Efficiency, and the Sustainable Energy for All agenda, to which Mali is committed as a member of the Economic Community of West African States.

Finally, the role of local authorities, for example city councils, must be increased. Local authorities have a direct legitimacy at the local level: they usually know the population well; they are in charge of local social and economic development plans; and they are usually elected. With the appropriate capacity and budget, they could become contracting authorities for projects and programs. The decentralization process that has been implemented in many African countries has reinforced the competencies and roles of local authorities in sectors like education and water management, but not yet sufficiently in the electricity sector.

Mali's challenges

Mali's electricity system largely relies on hydropower, resulting in high climate vulnerability; fossil fuels, creating a dependence on international markets; and interconnections with other countries which are themselves dependent on hydropower and fossil fuels. EDM, the privatized national utility, serves only urban locations through the national grid. Already heavily subsidized, EDM, like many central electricity utilities, has limited ability in managing broad-access deployment programmes. In other words, large parts of Mali must be served by mini-grids or stand-alone energy systems.

Mali's Agency for Domestic Energy and Rural Electrification (AMADER, after its initials in French) promotes rural electrification through public–private partnerships and regulates the sector. While its top-down large-*concession approach, aiming to* serve multisectoral electrification zones, was not successful, AMADER, through the Spontaneous Project Application for Rural Electrification programme (PCASER, after its initials in French), has supported projects that are smaller, demand-driven, locally based, and for the most part based on mini-grids. Priority is now given to hybrid mini-grids, usually based on a combination of diesel or biofuel generators and solar panels. AMADER has clearly contributed to the growth of rural electrification in Mali, but it faces a huge task given the high number of rural communes and villages it serves. Moreover, the projects have usually focused on short-term results, and the interest and involvement of local operators remain low; for example, 33 per cent of the subsidized installations were not operational in 2015.

Prevailing regulations still prioritize grid expansion over decentralized systems, and *tariff* models discourage private investment. Indeed, the maximum tariffs allowed in off-grid areas, set to limit the difference between them and the urban tariffs of EDM, which has a social tariff of 100 West African CFA francs(XOF) or around €0.15 per kilowatt-hour (kWh), are not sufficient to allow profitable and sustainable operation of rural mini-grids. A simplified analysis of electricity sales by EDM and the operators supported by AMADER shows that a fee (the word 'tax' is deliberately avoided) of XOF 5 or €0.008/kWh on the total electricity sold by EDM in 2013 would allow a cross-subsidy of XOF 200 or €0.30/kWh on the total electricity sold in the communities served by AMADER's projects during the same year. Such a cross-subsidy between grid-connected and off-grid access exists in very few countries (Peru is one). Of course, its implementation in Mali would be challenging given the political and financial issues (including the financial situation of EDM) and technical aspects (limited number of households connected to the grid).

Towards sustainable electricity access

The NGO Energía sin Fronteras conducted a national survey in October 2015 and a national workshop in November 2016, in the context of the project Access to Renewable Energy Services in Kita (PASER-K), funded by EuropeAid and Plan International. The objective of the survey was to identify barriers to sustainable electricity access in Mali and recommendations for overcoming them. Key results are summarized below; details are available in the complete takestock study and workshop synthesis.

Barriers

The key institutional and fiscal barriers identified by survey and workshop participants were lack of credit access by the private sector, households' low capacity to pay, lack of synergy with energy efficiency, EDM's financial difficulties, and policies that are overly focused on supply.

Technological and human barriers included lack of monitoring and efforts to identify lessons learned, the cost and variability of renewable energy, lack of data on energy needs by location, and lack of consumer awareness.

In contrast, lack of an up-to-date electrification plan, lack of clear objectives, insufficient participation by civil society in policy-making, and lack of technical expertise were not considered significant barriers.

Solutions

Actions at the institutional level recommended during the survey and workshop include the following:

- Better coordination or even integration of the Ministry of Energy and the different national energy agencies – AMADER, the Agency for Renewable Energy, and the National Biofuels Development Agency – to reduce complexity and conflicts over authority and finance.
- Clear definition of the conditions independent producers must meet to access the national grid.
- Territory-based definition of targets for rural electrification and renewable energy, with clear allocation of responsibilities (EDM for the national grid, AMADER for mini-grids, and the Agency for Renewable Energy for stand-alone systems). This would correspond particularly well to the need that has emerged under recent energy reforms to delink urban concessions from less commercially viable rural concessions.
- Actions at the business level include the following:
- Support for access to credit (concessional loans and loan guarantees).
- Promotion of clear and favourable conditions for public–private partnerships (tariffs, firmness of contracts, fair and transparent bidding process, conditions for connection to the national grid).
- Reinforcement of favourable fiscal measures.
- Promotion of local production of energy products.
- Definition and implementation of quality standards, labels, supplier certification (such as the Regional Certification Scheme for solar installers, under development in the West African Economic and Monetary Union).

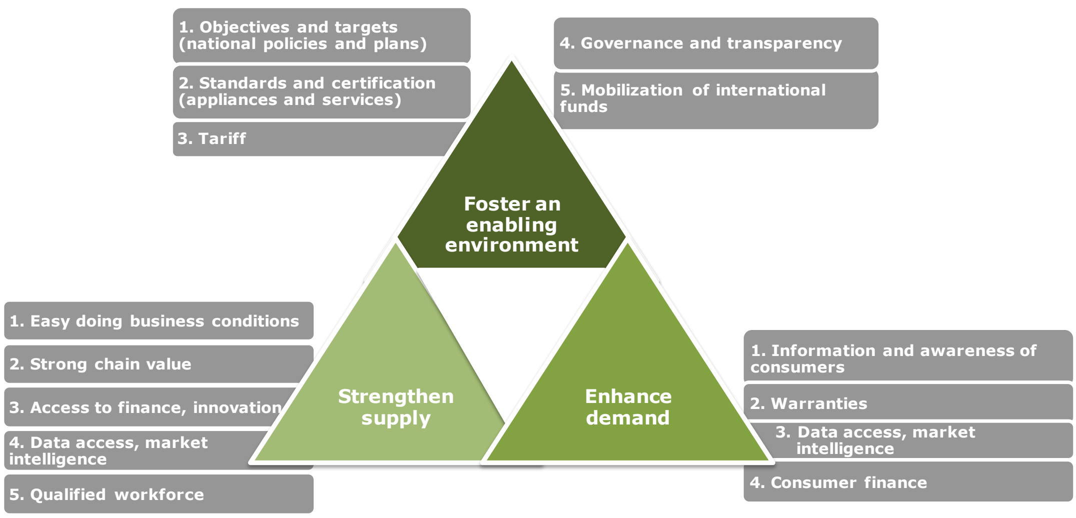
Actions on behalf of consumers and knowledge include the following:

- Support for microfinance and prefinancing of appliances.
- Providing information on available products and services.
- Studies of energy potentials, energy needs, successful business models, and products and expertise available in country, and dissemination of the results.

The Agency for Renewable Energy was expected to carry out the following roles:

- Definition and implementation of national renewable energy policies, including financial support, for example through a special tax on energy projects.
- Detailed analysis and mapping of the renewable energy potential, as

Framework for sustainable electricity access



well as of energy products and expertise available in Mali, by region.

- Promotion of demonstrations that allow consumers to see and test renewable energy products.
- Promotion of product and service quality by monitoring, certification (in collaboration with the Malian Agency for Standardization and Quality Promotion), labelling, and establishing a testing centre.
- Strengthening of its research and development activities related to new technologies.
- Definition and coordination of a national strategy for management of solar waste (e.g. batteries and panels).

An integrated framework

Taken together, these recommended actions form a framework for electricity access that has three pillars: a strong enabling environment, a solid supply of products and services, and a robust demand for these products and services.

While Mali is gaining experience in public–private partnerships and rural electrification concessions, sharpening of regulatory and financing mechanisms remains a challenge, as in many developing countries.

Electricity access and development

Electricity access is necessary but not sufficient to achieve development. Development needs a holistic approach that includes much more than the energy sector. Believing that energy access alone will ignite development creates the risk of moving from poverty without electricity access to poverty with electricity access.

Moreover, energy access has two elements: access to electricity services and access to modern and clean cooking. Around 3 billion people cook and heat their homes with solid fuels on open fires or traditional stoves, with severe health, gender, economic, and environmental impacts. Electricity and clean cooking access must go hand-in-hand to achieve sustainable development.

The ideas shared in this article are not intended to be prescriptive. In the end, national decision-makers, in collaboration with national stakeholders, must choose the strategies to achieve sustainable energy access for all.

RURAL ELECTRIFICATION: THE POTENTIAL AND LIMITATIONS OF SOLAR POWER

Anna Aevarsdottir, Nicholas Barton and Tessa Bold

Introduction

There is a general consensus that energy, in particular electricity, is a key input to economic development. This is highlighted in Sustainable Development Goal 7: ensuring affordable, reliable, sustainable, and modern energy for all by 2030. Despite this consensus, nearly 1.1 billion individuals around the world lack access to electricity. Of those, about 620 million live in sub-Saharan Africa (SSA). In addition, based on current grid expansion plans and population growth projections, it is estimated that 600 million people in SSA, primarily in rural areas, will remain without a grid connection in 2030 (*World Energy Outlook 2017*, International Energy Agency). In order to address these challenges, the Sustainable Energy for All global initiative, launched in 2012, aims to extend electricity access to the poor through both grid and non-grid small-scale electrification, especially in SSA. All this is done in the hope of unlocking the development potential of electrification as seen in the context of high-income countries. In this article, we discuss the potential and limitations of off-grid solar solutions in closing the gap in energy access by 2030.

Reduced cost of solar

Due to slow progress in expanding national grids, solar energy is being promoted by many as a decentralized and clean solution for rural areas that requires minimal infrastructure investment. This approach has become increasingly feasible as the cost of solar photovoltaic (PV) modules has been dramatically reduced over the past decade. In addition, the International Renewable Energy Agency estimates that the cost of solar PV cells will fall by another 59 per cent between 2015 and 2025 (*The Power to Change: Solar and Wind Cost Reduction Potential to 2025*, IRENA, 2015). These reductions in cost and improvements in efficiency have made solar energy a much more cost effective and feasible solution in developing countries where resources are limited. It is estimated that by 2030 solar could be the cheapest or second-cheapest energy source in the majority of SSA countries. (Brighter Africa: The Growth Potential of the Sub-Sahara Electricity Sector, McKinsey and Company, 2015).

Decentralization

Many developing countries, in particular in Africa, receive an abundance of solar irradiation throughout most of the year. It is estimated that SSA has about 11 terawatts of potential capacity, exceeding the projected capacity needed to meet demand by 2040 by a factor of 30. (*Brighter Africa: The Growth Potential of the Sub-Sahara Electricity Sector*, McKinsey and Company, 2015). Due to this irradiation potential and the rapid reductions in the cost of solar PV, solar home systems and solar-powered mini-grids may be particularly attractive solutions in rural and sparsely populated areas where the cost of extending the national grid may be prohibitive. They can be rolled out more quickly and with more limited capital investment than grid connections.

Consumer benefits

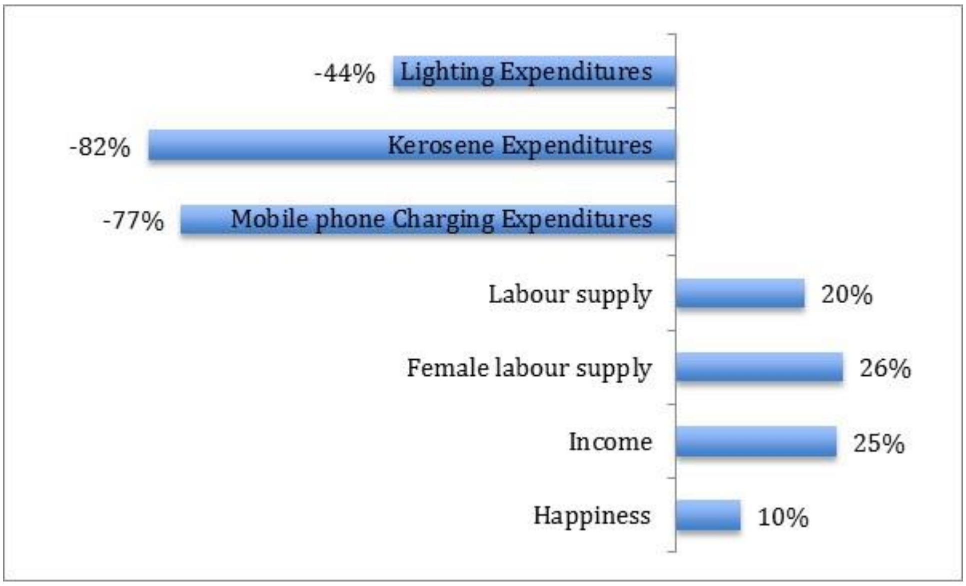
The availability of electricity along with other complementary investments, in particular lighting, is thought to affect development outcomes in a number of ways. The final outcomes of interest to policy-makers typically include improved learning and education, increased labour supply and household income, and better health. In turn, the pathways through which electricity affects the final outcomes can be characterized by a number of intermediate outcomes which themselves are also informative and of interest. These intermediate outcomes include, but are not limited to, additional productive hours for businesses, market work, and study; improved productivity during existing work and study hours; improved access to information (via mobile phones, radios, and the Internet); more efficient business practices through better access to communication technology; and improved indoor air quality as households switch to a cleaner energy source.

A number of papers have shown that with improvements in grid electricity such improvements in intermediate and final outcomes do indeed materialize, but have also pointed out the importance of complementary enabling conditions for the full benefits of electrification to accrue. These include reductions in energy expenditures, improvements in health and education, and increases in female employment ('The Effects of Rural Electrification on Employment: New Evidence from South Africa', Taryn Dinkelman, American Economic Review, vol. 101, pages 3078–3108, 2011).

Despite these positive findings on grid access, relatively little robust evidence exists on comparative impacts of solar energy access on household welfare. A handful of studies have explored the educational impacts of access to solar energy in rural contexts with mixed results. Encouragingly, a few studies on the immediate impacts of access to solar energy have found that solar lamps (a small-scale solar home system) significantly reduce energy expenditures and lead households to substitute away from poor-quality, high-emission light sources (see for example: A First Step up the Energy Ladder? Low Cost Solar Kits and Household's Welfare in Rural Rwanda, *World Bank Economic Review*, vol. 31:3, pages 631–649, 2017).

A recent study from rural Tanzania, in addition to confirming the impact on energy expenditures, found broader welfare impacts of solar lamp ownership. Specifically, it found that household expenditure on lighting decreases, as does expenditure on phone charging, both of which are clearly directly impacted by the ownership of a solar lamp sold as part of the study. Having more reliable access to mobile phones also increases use of mobile money by those who already have a mobile money account. Adults work more outside of the household and in jobs in which they can earn money, a result that is confirmed by analysing the time use of household members. This increase includes more women working in wage jobs. Comfortingly, adolescents do not increase their entry into the labour force or drop out of school more. Owning a lamp thus appears to create new opportunities by which households can increase their income, in part by exploiting the opportunity to charge others money for using the mobile phone charger. Not only do households report a higher income, but respondents also report feeling happier with their current situation in life (The

Summary of household-level impacts



Source: Aevarsdottir et al 2018. The Impacts of Rural Electrification on Labor Supply, Income and Health: Experimental Evidence with Solar Lamps in Tanzania, Anna Aevarsdottir, Nicholas Barton, and Tessa Bold, IIES Working Paper, 2018).

Impacts of Rural Electrification on Labor Supply, Income and Health: Experimental Evidence with Solar Lamps in Tanzania, Anna Aevarsdottir, Nicholas Barton, and Tessa Bold, IIES Working Paper, 2018).

Willingness to pay

Evidence from recent studies has shown that, despite the potential economic and noneconomic benefits from access to solar energy, willingness to pay is still quite low in developing countries. For example, a recent study found that only a small share of households in rural western Tanzania are willing to pay full price for solar lamps that produce enough power to provide lighting and charge a small appliance such as a mobile phone, even when offered the possibility to pay in instalments over four months (*The Impacts of Rural Electrification on Labor Supply, Income and Health: Experimental Evidence with Solar Lamps in Tanzania*, Anna Aevarsdottir, Nicholas Barton, and Tessa Bold, IIES Working Paper, 2018). However, the study also found that the energy expenditure savings accumulated over a two-year period would cover the cost of the solar lamp, without taking any other benefits into account. These results indicate that financing mechanisms and payment solutions that allow longer repayment horizons or pay-as-you-go models may significantly increase the take-up of small-scale solar home systems among rural populations.

A recent study from rural Rwanda concluded that relying solely on a market-driven approach to reach universal electrification is likely to be unsuccessful due to very limited willingness and ability to pay among poorer segments of the population, resulting in unrealistically long repayment periods (*Demand for Off-Grid Solar Electricity: Experimental Evidence from Rwanda*, Michael Grimm, Luciane Lenz, Jörg Peters and Maximiliane Sievert, Ruhr Economic Papers #745, 2018). Taken together, these results suggest that if the target of universal access by 2030 is to be achieved, improved financing mechanisms will need to be coupled with some form of subsidies, at least in the short run. These subsidies could be direct, by lowering the cost of the product, or indirect, by supporting extended payment periods.

Capacity limitations

Based on the evidence discussed above, off-grid solar appears to be a promising strategy for household-level electrification. It has been documented that even for grid-connected households, rural energy consumption levels are low, in the range of 50 to 100 kilowatt-hours per capita per year, enough to provide a household with lighting and mobile phone access and power a fan for five hours a day (*Africa Energy Outlook*, International Energy Agency, 2014;). These low levels of electricity consumption support the case for promoting solar to expand household energy access in rural areas. However, currently available off-grid solutions are unlikely to be able to affordably provide the electricity needed for larger-scale productive uses such as powering machinery for agricultural production or manufacturing. As an example, a small-scale rice mill needs an electric motor with the capacity of 2 kilowatts, which is roughly equivalent to the capacity provided by 700 units of the most commonly featured small-scale solar home systems in the studies reviewed above (*Africa's Pulse, Spring 2018: Analysis of Issues Shaping Africa's Economic Future (April),* World Bank, Washington, DC, 2018). In order to address the energy needs of industry and other productive uses, some form of mini-grid or on-grid solutions will be required.

Conclusions

Household-level electrification, even at low levels such as those provided by small-scale solar home systems, can bring substantial economic and noneconomic benefits to rural households in developing countries. However, limited willingness and ability to pay will need to be addressed through broader financing mechanisms, flexible payment schemes, and possibly short-term targeted subsidies to reach the Sustainable Development Goal of universal access by 2030.

DOES SOLVING ENERGY POVERTY HELP SOLVE POVERTY?

Catherine Wolfram, Ken Lee and Edward Miguel

Recent research has made us sceptical of a widely held belief.

'Access to reliable electricity drives development and is essential for job creation, women's empowerment and combating poverty.' This statement, attributed to Gerth Svensson, chief executive of Swedfund (a development finance group), neatly summarizes a commonly held belief in the energy and development communities.

This belief has backed a number of efforts to help the 1.1 billion people without electricity in their homes gain access. For example, the UN and the World Bank launched the Sustainable Energy For All initiative in 2011, the mission of which is to accomplish Sustainable Development Goal 7, 'Ensure access to affordable, reliable, sustainable and modern energy for all.' The government of India has announced an ambitious goal of connecting its 300 million un-electrified citizens by 2022.

But is the statement true? Or are some parts true, but not others? For example, maybe electricity drives job creation but not women's empowerment, or vice versa?

To answer questions like these, we conducted an experiment on grid electrification in western Kenya. We started by identifying households that were within 600 meters of an existing electric transformer but were not already connected to the grid. We next divided these households into two groups, treatment and control. We divided them randomly, meaning that each community had an equal chance of being in the treatment or control group. This mimics the well-established approach that drug companies use to test new drugs, and it means that, on average, the only difference between the two groups is the treatment they receive, which helps isolate the impact of that treatment.

In the treatment communities, our research team paid to connect up to 15 households to the electricity grid for free or at a steep discount. We worked closely with the electric utility and the rural electrification agency to ensure that the households were connected.

About 18 months later, we surveyed households in both the treatment and control groups. We asked all kinds of questions, like whether they were employed outside of subsistence agriculture (the most common work in these communities), how many assets the household had, and how good their health was. We gave the 12- to 15-year-olds tests, as one frequent assertion is that access to electricity helps students do better in school since they can study at night.

We next compared the answers from the treatment and control groups to measure the difference driven by electrification and found … nothing. No difference that our data could detect. The rural electrification agency had paid an average of more than $1,000 per household to connect them to the grid, and they were no better off by our measure 18 months later than households without a connection. Even the students' test scores were the same in the treatment and control groups.

Our results are intellectually fascinating, but at the same time discouraging. It would be nice to believe the widely held perspective that electrification will immediately drive growth. But here are some reasons we should be careful accepting this belief:

1) Correlation does not equal causation. There is likely nearly 100 per cent overlap between the 1.2 billion people in the world who do not have electricity in their homes and the world's very poorest citizens. But just because the lack of electricity is an easy identifier of the poor doesn't mean that giving them electricity will alleviate their poverty. In addition to electricity, they also likely lack running water, good sanitation, consistent food supplies, good education for their children, good health care, political influence, and a host of other assets that may be harder to measure but are no less important to their well-being.

2) We need to think about the timing of interventions. For very poor households, there may well be other interventions that have higher immediate returns and should be prioritized ahead of electrification. For example, previous work by one of us showed substantial economic gains from government spending on treatment for intestinal worms in children.

3) Electricity has value only when paired with electrical appliances, which can be expensive. To use electricity for more than basic lighting and cell phone charging, households need to be able to buy other things, which is hard if you're very poor. Households in our study hardly used electricity – only 3 kilowatt-hours per month, compared with the US average of 900 kilowatt-hours per month. And they barely bought any appliances.

4) Reliability matters. In many low-income countries, the grid has frequent blackouts and maintenance problems. This may make electricity less useful. In western Kenya, where our work took place, poor reliability is not caused by load shedding. In fact, Kenya right now has more than enough generating capacity. But nearly 20 per cent of the transformers in our study area were not working at some point during the first 18 months. And when they were down, they were unavailable for on average three months. Households may be reluctant to make investments that rely on electricity if the electricity supply is unreliable. But in much of the developing world, a grid connection is a connection to an intermittent supply.

It's also possible that our results can't be generalized. They certainly don't apply to enhancing electricity services for nonresidential customers like factories, hospitals, or schools. And maybe the households we're studying in western Kenya are particularly poor (although measures of well-being suggest they are comparable to many rural households in sub-Saharan Africa) or particularly politically disenfranchised. Or maybe our results would have been different if we were looking at electrifying a whole community or region and not just individual homes.

We were also concerned that 18 months was too short a time to see meaningful impacts. We recently went back to the households in the treatment and control groups and surveyed them again, about 32 months after they were connected. Unfortunately, the results were nearly identical to the results at 18 months – essentially no difference between treatment and control groups.

Results from several related experiments on the impacts of smaller-scale solar electrification solutions deliver similar 'meh' results. One study found that subsidized solar lamps helped western Kenyan families save $0.93 on kerosene per month, but they were not transformational. Children didn't study more; people didn't spend their time differently. A similar experiment in Rwanda found some evidence that children with solar lamps studied more, while another study found that children with solar lamps studied more but their tests scores were worse.

Addressing the needs of the world's poorest citizens is clearly important, and those of us who live with 24/7 electricity, Internet, running water, and locked houses cannot imagine living without them. But in a world of limited resources, we need to be focused on the best ways to address poverty.

We are not arguing that poor rural households should live without a grid connection forever. But it's important to think about the best sequencing for different development initiatives. Will an electricity connection have a higher payoff once a household has satisfied other needs, such as food security, education, and health care? The emerging evidence suggests that electrifying rural households may not be the essential key that we thought it was for the very poorest of the poor.

THE POLITICS OF RENEWABLE ENERGY IN EAST AFRICA

Emma Gordon

Less than a quarter of East Africa's population has access to electricity – the lowest electrification rate in the world. This, combined with the region's vast natural resources, represents a major opportunity for renewable energy investors. Solar irradiation levels are high due to proximity to the equator; wind speeds are some of the strongest on the continent; hydropower resources are plentiful; and the Great Rift Valley is a promising source of geothermal power.

This article compares the two largest economies in the region, Ethiopia and Kenya, to show how government policy affects renewable energy investment. Both countries have ambitious renewable-energy targets. The presence of both baseload and intermittent power sources means that both countries are able to aim for 100 per cent renewable power sectors. However, they both lack comprehensive power infrastructure and have a history of failing to meet peak demand, leading to frequent power shortages. Both countries are therefore seeking to expand their off-grid systems, particularly in rural areas, and to improve their on-grid generation capacity.

The investment experiences in Ethiopia and Kenya differ greatly. In Ethiopia the sector is only now opening up to private investment and the emphasis is on large, utility-scale projects. In Kenya, private companies have been present for decades and the country has become a hub for innovation in commercial off-grid and micro-grid systems.

These experiences reflect different political, regulatory, and security climates. In Ethiopia, the state dominates the economy and development is government driven. The power sector was, in practice, a state monopoly until 2017, and although the government is committed to growing renewable capacity, its approach has stifled growth, particularly in off-grid systems. The government retains a preference for large on-grid projects that it can control. Increasingly, investors are likely to be granted generous incentives to enter the Ethiopian market, and the government will support them with the necessary infrastructure development.

In Kenya, the market theoretically drives economic and social development, and as a result, the private sector has more freedom to operate. Consequentially, Kenya has become a hub of innovation for off-grid solutions. In 2015, East Africa accounted for over half of the global investment in off-grid systems, primarily in Kenya and Tanzania. Kenya's regulatory environment welcomes distributed energy systems, particularly in rural areas. Equally, from an investor's perspective, these projects reduce some of the biggest risks for foreign companies in Kenya, notably land access, security risks, and high levels of bureaucratic inefficiency and corruption.

Understanding country risk

The first major obstacle for many renewable energy projects in Africa is securing international financing. Reaching financial close can take over five years longer for African projects than for their counterparts in more stable investment environments. These delays are evident in the two largest on-grid developments covered in this report. The Lake Turkana Wind Power Project in Kenya took nine years to reach financial close; the Corbetti geothermal project in Ethiopia has taken seven years, and close is still an estimated 18 months away.

For many private investors, Africa presents an unfamiliar and potentially unstable operating environment. Given the limited sources of domestic financing, the majority of infrastructure projects on the continent have historically been financed by export credit agencies, multilateral institutions, or bilateral deals. In part, this is because only 24 of the 49 countries on the continent have been assigned a credit rating by the three major ratings agencies, and of those, only three have an investment grade rating. Despite this, the appetite for renewable energy projects in Africa has increased over the last few years. The cost of solar and wind equipment has plummeted, and several companies have demonstrated the commercial viability of off-grid and micro-grid solutions.

Understanding the political, regulatory, and security environment is a vital part of risk assessment. Among other things, it enables investors to establish whether they can expect a supportive policy environment, predictable tariffs, standardized contracts, and physical security for their assets. Each country presents a unique risk environment, and knowing the drivers of these risks should be a fundamental part of the project financing process.

Ethiopia

Ethiopia's abundant natural resources, ambitious electrification targets, and green credentials make a seemingly perfect combination for renewables investors. However, the state-dominated approach to economic development has limited private-sector growth. Since 2017, the government has opened the energy market to international investors. It has become a willing partner, offering generous incentives and supporting investment with the rapid construction of relevant infrastructure. That said, it offers less support to off-grid projects, which sit less comfortably with Ethiopia's centralized development approach.

Ethiopia has the second-highest installed generation capacity in sub-Saharan Africa at 4.5 gigawatts (GW), and a relatively advanced infrastructure network. In 2018, the World Bank estimated that 'nearly 80 per cent of the Ethiopian population [are] living within proximity of medium-voltage transmission lines.' Despite this seemingly strong enabling environment, only 43 per cent of the population, 24 per cent of primary schools, and 30 per cent of health clinics have access to electricity.

This contradiction is a result of policy decisions which have adopted a centralized, top-down approach to electricity expansion. Development of the country's power sector is governed by the Growth and Transformation Plan (GTP) – the national development plan that dictates the majority of prominent government policies. The GTP was first released in 2010 and was replaced by GTP II in 2016. The primary objective of the GTP is that Ethiopia reach middle-income status by 2025. Electricity generation and access are crucial to this goal. The first GTP called for a quadrupling of generation capacity from 2 GW to 8 GW. Despite falling short of this target, ambition only grew, with GTP II setting a target of 17 GW by 2020. Huge hydropower projects – notably the Grand Ethiopian Renaissance Dam – as well as five new wind farms, aim to bring the country to 5 GW by 2020.

A remarkable result of these development plans is that Ethiopia's power sector is one of very few worldwide to have an electric grid supplied almost exclusively by renewable energy. The idea of green growth is enshrined in the GTP, and at the UN Conference on Climate Change in 2015, the Ethiopian government pledged to cut emissions by an ambitious 64 per cent by 2030.

Such policy concerns preclude the development of fossil-fuel-generated power. However, there is still an urgent need for the government to diversify. It is currently overly dependent on hydropower, which is likely to become less reliable as droughts intensify. Hydropower projects will remain the main source of baseload power, supplemented by new geothermal developments, but these will need to be supported by intermittent sources such as wind and solar to meet peak demand.

Although the government has acknowledged that off-grid and micro-grid projects are important for rural electrification, the vast majority of power comes from large on-grid sources. For the next five years, the emphasis on utility-scale projects is unlikely to waver since it follows the government's centralized model.

Nascent but evolving regulatory sector

Until recently the electricity sector was a state monopoly run by the Ethiopian Electric Power Corporation. The government has acknowledged the need to increase capital investment in the electricity sector and would prefer to utilize public investment for infrastructure needs that cannot generate self-sustaining revenue. It has therefore committed to drawing in more international investors, and in 2017 it signed its first independent power production contract with Corbetti Geothermal. This represents a major turning point. In June 2018, the government also announced that it was considering opening up Ethiopian Electric Power to partial privatization. Despite these steps, the government maintains tight control over the sector and the direction in which it develops.

Private investment in the electricity sector is a relatively new phenomenon in Ethiopia, and regulation is still in its infancy. Over the last five years, the government has introduced new legislation to reform the sector and to drive up capital investment. Despite this, the country does not yet have key policies such as a feed-in tariff or net metering, mechanisms that ensure the price at which producers can sell power back to the grid. These regulation gaps undermine the ability to attract financing, which tends to require such policies in order to guarantee stability and profit predictability.

However, the government has proved a willing partner given that renewable energy – both on- and off-grid – is considered one of the so-called priority sectors. As such, investors are offered generous incentives including expedited decision making, tax breaks, and access to scarce foreign currency. Renewable energy investors are therefore likely to find fewer bureaucratic hurdles here than in neighbouring Kenya. That said, the environment for off-grid investors is far less developed, and all companies will need to contend with the on-going currency shortages.

Despite this progress, there are still numerous regulations that remain outstanding. The Ethiopian Energy Authority – the sector's regulator – is in the process of developing model power purchase agreements and implementation agreements for all renewable technologies. These model contracts will remove a significant amount of uncertainty for future investors. Crucially, this will include cementing important protections for investors, notably a generation payment guarantee in the event of the Ethiopian Electric Power Corporation defaulting. Alongside these standardized agreements, the Ethiopian Energy Authority has proposed introducing a feed-in tariff. A standardized feed-in tariff would reduce the need for complex bilateral negotiations for each project, and hence would likely facilitate smooth project planning and allow for more certainty while seeking access to finance.

For off-grid and micro-grid companies, there is even more regulatory confusion, particularly over licencing and their relationship with the rural electrification agencies. Private investment was authorized in 2013, but private-sector involvement has not grown significantly beyond the sale of solar home systems. The government has sought to maintain a level of control of the off-grid developments, and with support from the World Bank and other development institutions, runs most of the solar home system expansion projects.

There is an equal need for further harmonization of rural electrification agencies. Off-grid and micro-grid projects often need to coordinate closely with these agencies, since they are likely to be serving the same market. In Ethiopia, six agencies are involved in rural electrification, with overlapping and occasionally contradictory policies.

Comparatively low country risk

One of Ethiopia's noticeable advantages is that it has lower corruption risks than any of its neighbours. Most businesses do not report the same level of bribery demands and corrupt tendering as in Kenya, Tanzania, or Uganda. However, as reported by the World Bank in 2012, the high level of government involvement creates 'a widespread perception of hidden barriers to market entry' and 'an impression of favouritism'.

The government also has a track record for completing infrastructure projects without the repeated delays and cost inflation seen elsewhere in the region. This is most evident in the transport sector, but is also true of various hydropower projects that have come online in recent years. Much of this efficiency is due to the government's partnership with China, which provides the finance, equipment, and frequently the workforce for these projects. As in other priority sectors, the government supports China's contributions with tax breaks, quick decision-making, and easy land access.

This track record will encourage utility-scale renewables investors who rely on the expansion of transmission networks to get their electricity to market. As part of the National Electrification Program, the government plans to build 114 new transmission substations and 13,540 km of new 500 kilovolt to 66 kilovolt transmission lines by 2020. This will mark a dramatic increase from the 10,869 km of transmission lines in place in 2015.

A further boost for would-be investors are the government's ambitious power export plans and commitment to improving regional interconnectivity. Ethiopia is part of the East African Power Pool and is either already delivering or on track to deliver power to Djibouti, Kenya, Rwanda, Sudan, and Tanzania. This significantly expands the potential market for on-grid projects.

However, there are also risks. One of the most significant risks to companies operating in Ethiopia is currency shortages. Access to foreign exchange has been a major obstacle for businesses for years and has worsened over 2017 and 2018. Even in the priority sectors, which are given preferential access, businesses frequently complain about delays accessing currency of over three months.

Renewable energy investors also need to manage the risk exposure of their physical assets. These risks are significantly higher for large, utility-scale assets since off-grid and micro-grid projects are by nature small and dispersed. That said, Ethiopia has lower asset risks than many countries in the region. All land is government owned, removing access challenges but presenting investors with the risk of association with human rights concerns over forced displacements and government overreach.

Frustration over government land policies has, in the past, led to localized protests in rural areas. In 2015, it sparked mass protests across the Oromia region. These spread to Amhara and to a lesser extent the Addis and Somali regions, lasting until early 2018. Protests often attracted thousands of people, and in Oromia and Amhara led to attacks on foreign businesses, particularly those that were either associated with the ruling party or central to the government's economic policy. This included throwing stones (or in rare cases in Amhara, grenades) and burning company vehicles; in the worst cases, flower farms and textile factories were burned to the ground in Oromia.

Utility-scale renewable projects are likely to face high reputational and litigation risks due to their need to partner with the government. International investors have faced criticism for benefiting from the government's controversial land policies. Domestic and international rights groups have accused industrial and agribusiness projects of being complicit in forced relocations and inadequate compensation. The government has taken steps to improve compensation procedures, but it is highly unlikely that all individuals affected will have given free, prior, and informed consent.

Kenya

Kenya presents a very different investment environment to Ethiopia. The government has a history of welcoming private investment. Moreover, the power sector is much more influenced by market needs than by the government's vision for development. Like Ethiopia, renewables are the main contributor to the electricity mix, and ambitious electrification targets focus on renewable energy projects. The legislative environment for foreign investors is relatively well established for both off-grid and micro-grid projects. This reduces regulatory risk. However, the nature of the political system does present challenges, not least over corruption and access to land. As a result, unlike in Ethiopia, risks are higher for large, on-grid projects than for off-grid and micro-grid investments.

Kenya was one of the first countries in sub-Saharan Africa to liberalize its power sector, opening it to independent power producers in the 1990s. The sector is relatively well developed and has a strong track record. Electricity access rates have risen from 36 per cent of the population in 2014 to 56 per cent in 2016. The government is aiming for universal access by 2020.

As access increases, so will demand. Kenya has comparatively high per-capita consumption for the continent – 161 kWh, compared to 126 kWh in Nigeria, for example – and as the fourth-largest economy in Africa it has a burgeoning industrial sector. Peak demand therefore has the potential to increase from 2015 levels of 1,800 megawatts (MW) to 2,600–3,600 MW by 2020. This will exceed the current installed capacity of 2,333 MW. In response, the government is in the process of more than doubling its transmission network from the current 4,149 km.

Renewable energy accounts for 87 per cent of Kenya's power mix. It is at the heart of expanding power generation plans based on geothermal and hydropower. Both sources can provide baseload power, which would allow for a 100 per cent renewable energy mix. However, the government has not committed to this target. It has plans to develop a coal power plant in Lamu, and the Ministof Energy has made several statements indicating its intention to use natural-gas-powered turbines as a back-up power.

A unique feature of Kenya's electricity sector is its innovative use of off-grid solutions. The government has long recognized off-grid expansion as an effective means of rural electrification. There are at least 19 state-owned off-grid power stations in remote locations, primarily in the northern part of the country. Private companies are also allowed to generate and distribute power through micro-grids.

Of the 2,700 MW capacity addition planned over the next five years, 80 per cent is likely to come from private investment. This reflects Kenya's reputation as a business-friendly destination. Parties across the political spectrum support private investment, including in the renewable energy sector. Thus, Kenya's energy policy is likely to continue to support private investment.

The sector is further protected from political fluctuations by the partial privatization of utilities. Only the Geothermal Development Company and the Kenya Electricity Transmission Company are wholly state-owned enterprises. That said, political risk is still high compared to Ethiopia, due in large part to the high levels of ethnic competition throughout the system.

A major concern of investors in Kenya is the frequency and scale of political crises. In 2007–2008, political violence killed over 1,000 people and displaced over half a million. A decade later, elections in 2017 led to a Supreme Court intervention that annulled the election result and brought the country to a standstill in the six months until a new election was held. During election cycles, gross domestic product growth dips dramatically, as investors tend to delay decisions, fearing property damage and physical risk to staff as well as the potential for contract renegotiation or regulatory changes should power change hands.

A well-developed but inefficient system

The unstable political environment has numerous knock-on effects when dealing with government bureaucracy. As noted, corruption risks are particularly high and politicking can reduce the effectiveness of state institutions. This can affect efforts to expand the power infrastructure network, which is essential for many on-grid proposals.

That said, the government has created a relatively strong legislative and regulatory framework for renewable energy investors. Unlike in Ethiopia, this includes a number of targeted policies such as feed-in tariffs and net metering proposals. The plans for the sector are laid out in key policy documents, such as Vision 2030, the National Energy and Petroleum Plan 2015, and the 1997 Rural Electrification Master Plan. These policies have been translated into two key laws and regulations: the Sessional Paper No. 4, 2004 on Energy, and the Energy Act 2006, which is due to be replaced by the Energy Bill 2017, currently in draft form. The new bill contains a number of key changes:

- Removing Kenya Power's monopoly to make the distribution market more competitive.
- Replacing the feed-in tariff policy with competitive auctions.
- Introducing net-metering to support private, off-grid consumers.
- Introducing royalties of 1–2.5 per cent for geothermal producers for the first decade, after which they will rise to up to 5 per cent.

Despite the delays in introducing the new Energy Bill, the presence of such a well-developed regulatory framework is a strong draw for international investors. Crucially, Kenyan power purchase agreements (PPAs) use a standardized model following government guidance. This provides additional contract certainty for investors. It also reduces regulatory uncertainty for utility-scale investors by establishing the terms under which they sell their power back to the grid. Additionally, under a collection of legal notices approved in 2015, renewable energy projects receive a number of tax exemptions – including from withholding tax, stamp duty, export duty, and VAT and customs tax on imports.

Renewable energy projects under 50 MW can currently apply for feed-in tariffs, which were first introduced in 2008 and last revised in 2012. This allows power producers to sell their electricity to an off-taker for a fixed price, over a set period. This system is considered beneficial as it allows investors to guarantee their profit margins. However, in Kenya it has caused delays during licensing discussions and has led to the growth of speculation in the market.

The government will replace the current feed-in tariffs with a system of competitive auctions under the Energy Bill 2017. This will allow for greater competition over pricing, in theory producing a better result for end users. For investors, auctions still provide price stability, but they are likely to have to offer lower tariffs, potentially reducing their profit margins. That said, competitive auctions have proved highly effective elsewhere on the continent, including in South Africa and Zambia, where they have produced record low tariffs.

The tariff system has been particularly challenging for off-grid and micro-grid projects, where it has resulted in lengthy negotiations for licences. Private operators generally charge a higher tariff than the universal rate and offset the high tariff with a low connection rate, based on the assumption that usage will be high. This tension has resulted in the government rejecting several commercial tariff proposals, significantly delaying project implementation and putting investor profit margins at risk.

Even for larger projects, progress can be slow. Vestas Wind Systems first signed their PPA in 2010, but construction on the Lake Turkana Wind Power project did not begin until 2016. While there is a strong government impetus behind these projects, they are still stymied by the same long negotiations and high transaction costs as other infrastructure projects. The politicization of negotiations can also add to the challenge of finding foreign backers for projects. For example, in 2012, the World Bank withdrew from a deal to guarantee funding for the Turkana Wind Project due to a disagreement over the terms of the PPA.

Despite having a better regulatory environment than Ethiopia, Kenya's bureaucratic inefficiencies and high levels of corruption affect a significant proportion of interactions with the government. Further, the level of tribalism within the political system leads to cyclic disruption associated with elections and a complex social environment for investors to navigate. Land politics present a particularly high risk, with many large-scale projects facing either protracted litigation or violent protests in connection with their physical assets.

Conclusion

The renewable energy sector in East Africa presents a vibrant investment environment with opportunities for large on-grid projects in geothermal and wind as well as commercially viable distributed solar investments. However, the prevalence of political, regulatory, and security risks can contribute to long delays in project finance. In some cases, investors have pulled out of projects or closed operations down entirely as a result of regulatory uncertainty or a physical threat to their assets. Yet despite this, an increasing number of private power producers persevere to reach financial close, and over the last year off-grid ventures have completed record funding rounds.

East Africa is home to one of the largest hydropower projects in the world (the Grand Ethiopian Renaissance Dam in Ethiopia), one of the largest planned geothermal projects in Africa (Corbetti in Ethiopia), and the largest onshore wind development in Africa (Lake Turkana in Kenya). The region is also home to several record-breaking off-grid ventures, including M-Kopa in Kenya and Off Grid Electric in Tanzania.

These examples hint at one of the key findings of this article: that Ethiopia looks more favourably on large utility-scale projects, while Kenya presents opportunities in off-grid innovation. This is partly driven by the differing risk landscapes in these countries. In Ethiopia, the risk is primarily in the political and regulatory stage, whereas physical asset risks are lower. The country's less developed regulatory system means that investors are likely to rely more on government support to push ahead with a project. The government has proven more willing to throw its weight behind large utility-scale investments, while gaps in the legislation still prevent the rapid expansion of private off-grid investment.

Meanwhile, in Kenya, asset risks are significantly higher and regulatory gaps are fewer. This creates an environment where projects with a large physical presence are at a disadvantage. Problems with land access and a high risk of protests can cause major delays to large, on-grid projects but pose little to no risk to distributed off-grid projects. Equally, since the legislative and regulatory environment is more developed, it includes provisions covering off-grid and micro-grid systems. This, combined with the boom in mobile payment technologies, has allowed for the roll-out of pay-as-you-go solar systems that support government electrification targets while still providing returns to international investors.

AID AND THE DESIGN AND IMPLEMENTATION OF POWER SECTOR REFORM PROJECTS IN SUB-SAHARAN AFRICA

Neil McCulloch, Esméralda Sindou and John Ward

Although some African countries have made great strides in off-grid electrification, the bulk of Africa's population is still more likely to achieve access through the grid. However, the extension of grid access in sub-Saharan Africa has been painfully slow. One reason is that the power sector in many African countries is loss-making and often insolvent (see here). Development partners have therefore attempted to support power sector reforms to improve the viability of the sector, improve reliability, and extend access. Often power sector reform has been seen as a necessary condition for advancing electrification in Africa, given the shortage of government capital budgets and the reluctance of the private sector to invest in a loss-making sector.

These efforts have frequently encountered challenges associated with the political sensitivity of such reforms and the difficulties that donors face in responding to these challenges. As a result, there has been a resurgence of interest in the political economy of donor engagement in reform processes. A series of studies have suggested that projects that take a flexible and adaptive approach to reform have been more successful. Donors have been urged to focus on problem solving through an iterative process, while projects should 'crawl the design space' for solutions (see here). Similarly, donors are increasingly recognising the need to 'think and work politically' (see here) and to 'work with the grain' of the domestic political reality (see here). There is also a growing literature of comparative case studies that argue that aid programmes which are flexible, long-term, and locally owned are likely to be much more effective in achieving sustainable change than more traditional 'linear' programmes (see here).

Donors have been paying attention to this literature and are increasingly recognizing that an appreciation of the politics of the sectors and countries in which they are operating is essential for successful and sustainable reform. This article examines how donors have tried to take political context into account in their support of power sector reform in sub-Saharan Africa. In most countries, power systems are centralized, mainly based on a national grid, and although electricity is part of the development narrative of most countries, it tends to be controlled by a domestic elite and is a significant source of rents. Thus the characteristics of the power sector make accounting for political considerations particularly important.

Although there is already a literature on the political economy of power sector reform, rather little has been written about the role of donors and the extent to which they have taken knowledge about the politics of reform into account in the design and implementation of their programmes in Africa.

In this article we look at the following questions: To what extent have donors analysed the underlying political constraints that they face? Have donors significantly shifted the nature of the power sector reform programmes which they implement as a result of a better understanding of the political context? Are they taking on board the lessons from recent research on 'thinking and working politically', and if so, how? Are there general lessons that can be learned about what sorts of approaches to power sector reform are more, or less, successful and how this varies by context? We conclude with a summary of the lessons about how donors might respond more effectively to the political challenges associated with power sector reform.

A brief history of donor engagement in power sector reform

Although donors have been involved in supporting power sector investments since the 1950s, the nature of development partner involvement in power sector reform in developing countries is rooted in the transformations that affected the sector in OECD (Organisation for Economic Co-operation and Development) countries in the 1980s. During that time, a combination of political, financial, and technical factors triggered power sector reforms in the United Kingdom, Chile, and Norway. These countries' experiences appeared to demonstrate the benefits of such reforms, which were then followed by several other industrialized nations and some developing nations from the early 1990s. Since then, power sector reform has been advocated by the development community, including the World Bank, the Inter-American Development Bank, the European Bank for Reconstruction and Development, and other international agencies, such as the World Energy Council. Donors have played a major role as the architects of reforms in the power sector, and have often attempted to initiate reform through the provision of technical assistance and capacity building programmes in developing countries.

At first, most development partners typically implemented a somewhat uniform approach to power sector reform. The approach taken in OECD countries crystallized into a standard model for restructuring the sector, which followed a logical sequence of distinct steps: corporatization, commercialization, legislation, regulation, restructuring, privatization, and competition. The development community promoted reform out of a belief that the standard model would enable the transformation of poorly performing energy systems in developing countries, promoting growth and improving access for poor populations. In the words of one former senior donor official from a major multilateral donor, 'there was, in the early 1990s, a strong belief that one size did actually fit all.'

However, the application of the standard model of reform in developing countries yielded rather modest results, as it faced significant political barriers. The consensus in the literature is that the standard model failed for three main reasons.

First, it often failed to take account of the vast differences between circumstances prevailing in developing countries and those in the OECD countries where it was first implemented.

Second, it failed to map out a feasible pathway for reform. As Victor and Heller (2006) summarized it, 'The standard textbook for reform focuses on the end point, namely an unbundled, privately owned and competitive power sector, not on the steps that governments need to take towards that end.'

Third, many reform attempts failed to take account of the underlying political constraints facing decision makers. In almost all countries, reform of the power sector is an extremely sensitive area. Electricity is part of the development vision of all countries and therefore brings significant political benefits to leaders who can control the price of and access to this key developmental service. Economies of scale mean that large financial flows are involved in procuring power production, transmission, and distribution systems. The centralized nature of the technology concentrates control in the hands of relatively few powerful individuals. As a result, the location of transmission and distribution lines can be driven by electoral considerations, power may be rationed to influence voters, and power generation may fluctuate with the election cycle. Utilities have historically been used to serve the broader patronage system and have become large employers (see here). As reforms often emphasize restructuring utilities, they have faced strong resistance from labour unions. Reforms have also encouraged cost-reflective pricing, but the associated price increases have resulted in popular uprisings in several countries including Argentina, Ghana, India, Indonesia, and South Africa.

Thus, rather than the standard model, the reforms of the last two decades have generated a wide variety of hybrid structures (see here) for a recent classification of different systems in Africa). In each case, these reflect the outcome of a complex and context-specific contestation both between domestic actors (utilities, independent power producers, regulators, finance ministries, energy ministries, and political leaders) and between domestic and international actors (independent power producers, donors, and other financiers).

By the early 2000s, the donor community was conscious of the difficulties being encountered in the implementation of power sector reform in developing countries. The World Bank commissioned a major review of its power sector operations (see here); it concluded that 'the most important lesson from reforming power markets in developing countries is that "cookbook" solutions for reforming their power markets are ruled out by the extensive range of economic and institutional endowments of these countries.'

The consequence of this reappraisal was the abandonment of the one-size-fits-all approach. The World Bank issued new operational guidance to its staff, which emphasized context specificity and the importance of the political dimensions of reform. In particular, a stronger focus was put on identifying 'stakeholders with the incentive and influence to press for improved performance' and 'top-level political decision makers' who will be able to champion the reform process.

The last decade has therefore seen considerable experimentation by development partners and closer attention to the political context. But donors still face considerable challenges in navigating the complex politics of power sector reform, and it is not clear whether the deeper understanding of context has yet translated into donors undertaking different interventions in the countries that they support.

Lessons learned

Our analysis of the research literature and documentation from donor projects and our interviews with donor officials suggest some general lessons for policymakers, both in development partners and developing country governments.

1. Analysing the underlying politics of change in a country is valuable – but only if used.

Donors still undertake remarkably little serious formal analysis of the political context in which reforms are undertaken. Reforms are viewed as technical, with the result that the only analysis undertaken prior to the implementation of projects is assessment of the different technical aspects of the project, rather than assessment of the wider political context and the incentives for various stakeholders.

This is not because donor officials fail to understand the political context. However, the instruments at their disposal, the pressure to disburse, and the processes with which they have to comply seem, at best, to discourage a slower and more reflective approach to engagement. It appears to be difficult *not* to pursue reform, even if there is evidence that the particular pathway being proposed is unlikely to be successful.

2. Flexibility is important – but there are reasons why it is difficult.

There is widespread agreement among donors that programmes should be designed to be flexible and adaptive (see here), since this allows donors to shift focus to take account of changes in government and key personnel in counterpart organizations, as well as enabling implementing partners to experiment with alternative approaches.

However, there are significant structural and procedural reasons that flexibility is difficult. For example, the US Agency for International Development receives funding from the US Congress that is allocated by sector and by country, inhibiting the flexibility to shift resources from less effective to more effective areas. Complex reforms often require multidisciplinary approaches, but donor staff are often organized by sector and discipline, making building a multidisciplinary team difficult. Certain types of donors are constrained to work with particular counterparts – for example, in the power sector, projects often must work through the ministry of energy, even where the ministry's influence is a key constraint on reform.

Flexibility is particularly difficult when it comes to stopping on-going initiatives. Once a project is approved, donor officials and implementers are obligated to make a success of it. This provides strong incentives to continue, even when external, often politically induced, changes have made the chance of success slim.

3. Dialogue, trust, and personal relationships are of critical importance for reform.

The long-term nature and sunk costs of power sector reforms make the issue of trust particularly important. Most successful reforms have involved the construction of an effective working relationship through intensive and repeated interaction, often over a long period of time. Counterparts often want donors to listen more and lecture less. As one experienced donor official put it, 'There is no substitute for an experienced and credible [donor] staff member who has the trust and confidence of the key decision maker.'

However, donor structures and training may make building trust more difficult than before. The high burden of process compliance required of donor staff takes time that might otherwise be spent engaging key stakeholders. In part, this bureaucracy reflects risk aversion associated with donor-country domestic political concerns, or a results agenda requiring officials to 'prove' that aid is working. Frequent rotation of donor staff also undermines the ability to build long-term relationships and to obtain a good understanding of the country's recent history.

4. Mental models matter.

Notwithstanding the evidence suggesting that the standard model has not worked in many developing countries, the model's core elements still appear to hold sway in the thinking of development partners and some government officials. In part, this is because there is no other compelling mental model to which to refer. Rather, path-dependent hybrid models have begun to develop based on local experimentation within different political contexts. However, most international consultants, on whom donor officials depend, are still most familiar with the standard model. As a result, it has been difficult for donors to shift their advice, whilst developing countries have found it hard to gain donor acceptance of the somewhat expedient and path-dependent approaches implemented in practice.

5. There may be opportunities to build domestic demand for reform.

Development partners have put relatively little effort into building a wider domestic constituency for reform in the countries in which they operate. Rather, most donors appear to have interpreted 'country ownership' to mean government ownership. This may reflect the fact that, in some countries, donor projects are tightly controlled by the government, which may be unsympathetic to activities that attempt to support advocacy activities. However, the lack of interest in building coalitions in support of reform is surprising, given the growing evidence of the importance of building broader coalitions to achieve sustainable reform.

Conclusion and recommendations

Whilst development partners are often fully aware of the political nature of reform of the power sector, they devote little attention to the analysis of political constraints, and what analysis there is has little influence on the nature of programmes that are put in place. Many development partners appear to be unaware of the emerging aid modalities for engaging with dynamic political contexts or, for structural or political reasons, are unable or unwilling to adopt them.

At a minimum, programme design should start with a detailed analysis of the underlying motivations of the key actors and institutions to identify reform pathways that are politically feasible rather than just technically desirable. Development partners need to balance activities that are consistent with the current political equilibrium; with those supporting legitimate domestic actors to challenge the status quo. And researchers need to test whether programmes that adopt more politically savvy approaches are actually more effective and how their success or failure depends on the nature of the political context and the way in which they are implemented.

The answers to these questions could help donors to support African countries to reform their power sector in ways that are politically feasible while also advancing the extension of electricity access to all.

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ELECTRIFICATION IN SUB-SAHARAN AFRICA: THE ROLE OF INTERNATIONAL INSTITUTIONS

Simone Tagliapietra

Introduction

Africa's access to electricity varies by region: North Africa is almost entirely (99 per cent) electrified; in sub-Saharan Africa excluding South Africa (SSA), electrification rates in most countries are below 30 per cent; and South Africa is predominantly (86 per cent) electrified. Lack of access to electricity in SSA is even more dramatic in rural areas, where electrification rates average 16 per cent, compared to 99 per cent in North African countries and 71 per cent in South Africa.

Since 2014 the number of people without access to power in SSA has declined, as electrification efforts have surpassed population growth. Decentralized renewable-energy solutions play an increasing role in this trend. However, around 590 million people in SSA continue to lack access to power, more than half of the world's total.

Lack of access is not the only component of SSA's electrification challenge. Even among people who do have access to electricity, there are wide disparities in annual per capita consumption between the three regions: 225 kilowatt-hours (kWh) in SSA – and as little as 100 kW in rural areas – compared to 1,500 kWh in North Africa and 4,200 kWh in South Africa.

Thus, two-thirds of SSA's population does not have access to power, while the remaining one-third cannot consume as much as it would like, due to regular blackouts and brownouts resulting from structural problems in the electrical system.

Making power available to all by 2030, in line with the UN Sustainable Development Goals, is therefore a major challenge for Africa, notably for financial reasons.

The International Energy Agency estimates that cumulative investments between 2017 and 2030 under current policies and commitments are less than one-fifth of the amount needed to achieve universal electricity access in SSA, which it estimates at $454 billion, an average of $35 billion per year.

How to meet this substantial investment requirement? The issue is complex, and no simple solution exists. However, two points seem to be essential:

1) SSA countries should reform their power sectors to facilitate international investment.
2) The international public financing made available for Africa's electrification should be better used, in order to encourage international private investments in the sector.

Sub-Saharan African countries should first reform their power sectors to facilitate investments

SSA countries should be the key drivers of their own energy development. They have the resources to do so, and to realize the policy ambitions of governments throughout the region to improve the reliability and coverage of their power systems. But this potential can only be unleashed by creating sufficient opportunities for investment. This challenge extends well beyond the power sector, and meeting it will require a reduction of the risks arising from macroeconomic and political instability and from weak protection of contract and property rights. But it will also require specific reforms in the power sector as well – in particular, two key reforms:

1) *Reform of power utilities* – today, SSA power utilities are not financially sustainable. Almost all of them run in quasi-fiscal deficit and thus need to be subsidized by the state.
2) *Reform of energy subsidies* – SSA countries spend around $25 billion every year in energy subsidies, mainly of inefficient and wasteful electricity utilities and, in certain cases, of old forms of energy, like kerosene.

The key role of international public finance initiatives in fostering Africa's electrification

International public finance institutions, such as multilateral development banks and national development agencies, could channel international private investments into Africa's power sector by establishing dedicated blended finance tools and/or risk-sharing mechanisms.

The combination of political risks (e.g. corruption), commercial risks (e.g. capacity of consumers to pay their bills), lack of stable power market regulatory frameworks, and lack of adequate power infrastructure, currently discourage private investment. On the other hand, international official development assistance and other official flows to the African power sector have quadrupled over the last decade, increasing from $2 billion in 2005 to $8 billion in 2015.

The World Bank Group, European Union (EU) institutions and member states, and the African Development Bank disbursed most of the funds in the sector, while other players – including the United States, the Climate Investment Funds, the Arab Fund for Economic and Social Development, and the OPEC Fund for International Development (OFID) played a far smaller role.

Investors have focused on different energy sectors, with the World Bank Group investing mainly in non-renewable power generation (particularly coal), the EU in renewable power generation (hydro, wind, and solar), and the African Development Bank in power transmission and distribution infrastructure. Their geographic focus has also been different. For instance, over the last decade the EU was the main international public investor in North Africa, followed by the Climate Investment Funds, the Arab Fund for Economic and Social Development, OFID, the United Arab Emirates, and others. The African Development Bank also played a significant role in the region, while the World Bank Group was only marginally engaged there. In SSA (excluding South Africa), the major investors were the World Bank Group, the EU, and to a lesser extent the African Development Bank. The African Development Bank and the World Bank Group were the key players in South Africa.

China has also played a substantial role in Africa's power sector, but that country does not disclose precise information about its development finance flows to Africa, and only unofficial estimates exist. According to the International Energy Agency, Chinese companies (90 per cent of which are state-owned) were responsible for 30 per cent of new power capacity in SSA between 2010 and 2015, with a total investment of around $13 billion. Chinese contractors have built or are contracted to build 17 gigawatts of power generation capacity in SSA from 2010 to 2020, equivalent to 10 per cent of existing installed capacity. These projects are widespread across SSA, in at least 37 of the region's 54 countries. Chinese contractors primarily focus on large projects involving traditional forms of energy like hydropower (49 per cent of projects 2010–2020), coal (20 per cent), and gas (19 per cent); their involvement in modern renewables remains marginal (7 per cent).

Africa is also part of China's One Belt, One Road initiative. That initiative includes not only the 'Silk Road economic belt' stretching from Asia to Europe, but also the 'maritime Silk Road' linking China and Europe via the Indian Ocean littoral and East Africa. According to a Boston University study, China has invested about $128 billion in energy projects in Belt and Road countries since 2001. Of this investment, $4.1 billion has targeted Africa – predominantly to develop coal-fired power plants. In this initiative, China thus seems not to consider the environmental and social issues that currently prevent the majority of international financing institutions from supporting coal projects in Africa. China's focus on coal and big hydropower projects makes international financing institutions' support for solar and wind energy projects in Africa even more important.

Limitations to the current system

The increasing international support for Africa's electrification is good news for the continent, but it is not sufficient to bridge the gap between current investments and those required to provide access to power to all by 2030. The most promising way to bridge this gap is to scale up international private investment; and for that to occur, domestic reforms are needed to create a viable and attractive investment environment.

International financial assistance for Africa's electrification should also evolve to assert more leverage over private investors, and over African governments by incentivizing energy market reforms. In this regard, the main issue is coordination.

Around 60 international initiatives – originating in Europe, America, the Middle East, and Asia – are currently contributing to the development of energy markets and the improvement of access to power in Africa.

As outlined by the Africa Progress Panel in 2015, Africa's energy needs are poorly served by such a fragmented system. This because funding is generally delivered through overly bureaucratic structures that combine high transaction costs with low impact, resulting in most finance being earmarked for small-scale projects rather than sizeable programmes.

Global financing initiatives for Africa's electrification are broad in scope and eclectic in focus. Taken in isolation, this might be considered as good news, as it signals widespread global support for Africa's electrification. However, when considering that 92 per cent of the last decade's international financial support to Africa's electrification came from only three sources (the World Bank Group, African Development Bank, and EU), there likely remains a coordination issue between these large well-established funders and the multitude of new initiatives.

The EU's presence appears particularly fragmented, with 26 initiatives originating from member states and EU institutions. The variety of member states' initiatives is understandable, as each country has its own political and commercial interests. What is less understandable is the fragmentation of EU institutional initiatives. This fragmented system seems to favour overlaps, inefficiencies, and higher transaction costs. European taxpayers' money would arguably be better spent if channelled through a single facility, allowing policy consistency, elimination of overlaps, reduction of transaction costs, and therefore higher efficiency and impact.

The World Bank Group, African Development Bank, and United States have streamlined their activities, focusing resources on a few initiatives, and thus do not appear to be contributing to the fragmentation problem. For instance, the African Development Bank, in addition to its traditional financing tools, has established two initiatives: The New Deal on Energy for Africa (a public–private partnership between the Bank, African governments, and the global private sector aimed at establishing innovative financing for energy projects), and Africa50 (an infrastructure fund owned by the Bank, African governments, and global institutional investors, created to mobilize long-term savings to promote infrastructure development). The United States mainly acts through Power Africa, a public–private partnership launched in 2013 involving 12 US government agencies, African governments, other multilateral partners, and more than 100 private-sector partners including energy companies, investment banks, equity funds, and institutional investors.

Making the most of international assistance

Electrification is a major requirement for socioeconomic development in SSA. Achieving it requires joint action by SSA countries and the international community.

SSA countries should reform the governance of their energy sectors – in particular, of power utilities and energy subsidies. Without this, they will not attract international private investment at the scale needed to achieve electrification or other elements of Agenda 2030.

International financial and development institutions need to offer more than financial support for Africa's electrification. Increased technical assistance is also critical. International institutions with solid experience in infrastructure financing could enhance Africa's 'soft' infrastructure of national governments and institutions by supporting the development of sound energy policies, regulations, incentive systems, sector reforms, corporate governance, and transparency and accountability best practices. Programmes like the New Deal on Energy for Africa and Power Africa, described above, are already contributing to this effort.

Calls for better coordination and cohesion in the development arena are ubiquitous, and there are relatively few success stories. Still, the way to make the most of the global financing initiatives for Africa's electrification could be to establish a coordination or information-sharing mechanism to better track the sector's rapid changes and keep key actors and stakeholders informed. Given its global outreach and considering its attention to the issue of energy access, the International Energy Agency could be the right institution to run such an initiative.

International financial support is particularly vital for the three-fifths of the SSA population living in rural areas. Developing small-grid and off-grid power solutions in rural areas is often highly challenging due to geographical or economic constraints. With declining costs and increasing performance for small hydro, solar photovoltaic, and wind power generation as well as electricity storage and control systems, small-grid and off-grid renewable energy systems could become game-changers for SSA rural electrification, in a decentralized and modular manner. However, these innovative energy solutions face two major barriers.

1) While their operating expenses are low, they require substantial up-front capital investment. In SSA, country, regulatory, and commercial risks substantially increase the return expectations of investors and thus any project's capital costs. This discourages capital-intensive energy options and encourages less capital-intensive, conventional energy technologies.

2) They are characterized by high transaction costs. For instance, the transaction cost per kWh of electricity produced from a hydropower plant is lower than the sum of the costs of the hundreds of transactions required for comparable capacity from solar photovoltaic or wind power.

International financing institutions could play a truly vital role in making a stronger case for investment in rural electrification solutions.

Europe would need to make a particular effort to coordinate its many existing programmes in the region. This is the only way Europe can make a significant contribution to SSA's electrification challenge, in terms of both crowding-in private investments and stimulating SSA countries' energy sector reforms. Coordinating current and prospective European programmes for SSA electrification though the recently established EU External Investment Fund could represent a pragmatic way to achieve this.

Electrification and climate change

In addition to its relevance for SSA's socioeconomic development, electrification has important implications for climate change. The United Nations has predicted that Africa will experience greater population growth than any other region, from 1.2 billion in 2015 to 2.5 billion in 2050. Energy demand is likely to grow accordingly. Thus, ensuring a sustainable energy mix for Africa is crucial to avoiding a negative impact on climate, and efficiently supporting Africa's sustainable electrification should be seen by international actors as an important component of their overall climate change mitigation effort.

In this regard, the potential for a new global North–South financial cooperation should also be considered. Financial resources from Europe and North America could be invested in green assets in the global South, and notably in Africa. This would allow investors to earn higher returns, while helping to improve living conditions for the world's poorest and to mitigate climate change. It is up to African countries themselves to initiate this virtuous cycle – by making the reforms necessary to create a favourable investment environment.

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