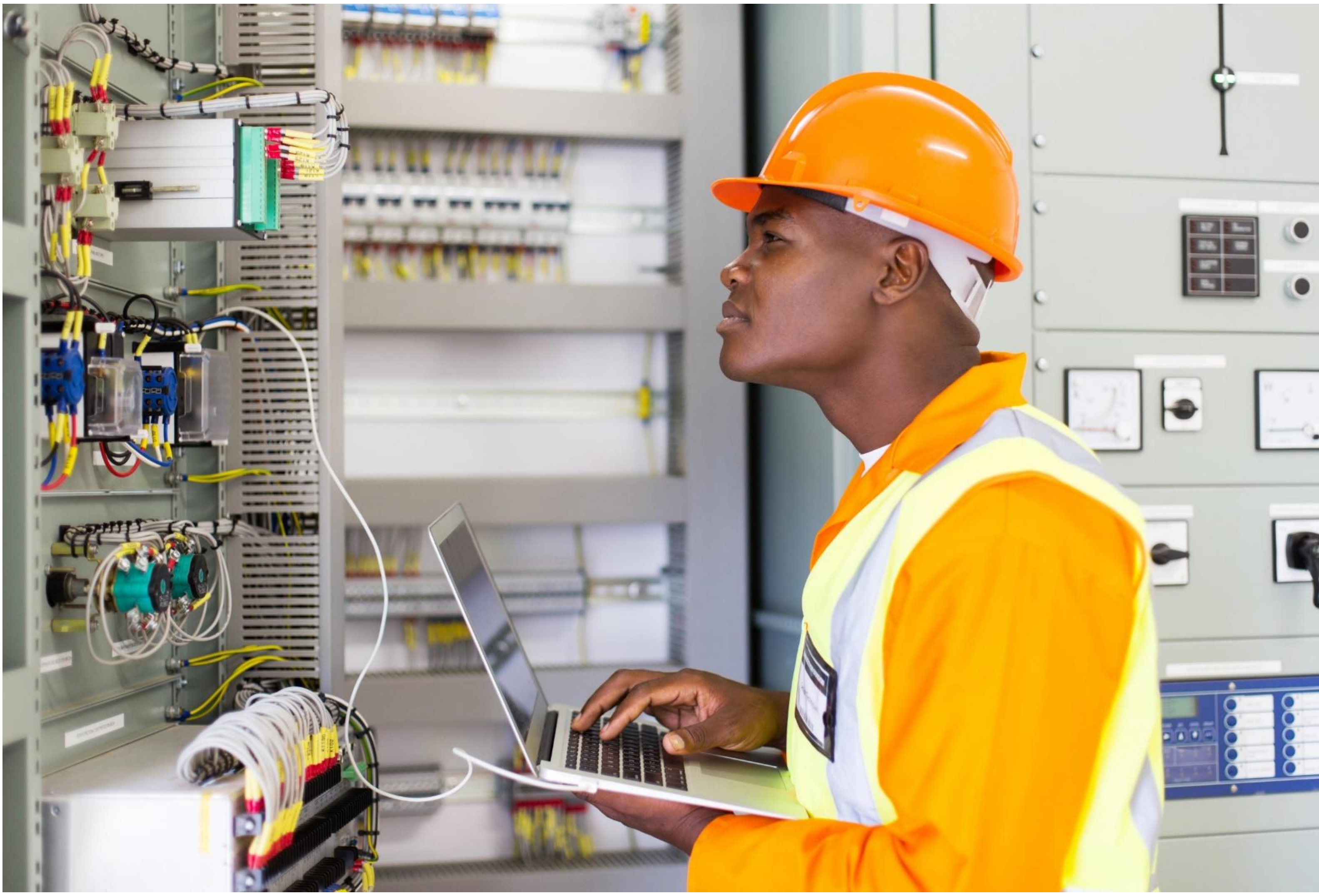
Energy and Economic Growth
Applied Research Programme

Disruptive innovations in smart electricity systems: Opportunities and challenges for sub-Saharan Africa

Energy Insight

Stuart McKinnon, Rachel Mulhall, and Emma Owen



Oxford Policy Management

CATAPULT Energy Systems

UKaid from the British people

1. Introduction

Global energy use has to date been dominated by fossil fuels – a key contributor to CO_2 emissions. However, the international community has committed to reducing the amount of greenhouse gases (GHGs), including CO_2, emitted into the atmosphere, to limit the extent of anthropogenic climate change. In parallel, it is starting to acknowledge the impact of particulate emissions from fossil fuels on air quality and human health. These factors are driving countries to transform their energy systems so they are clean, smart, and affordable for the citizens they serve. A large part of the energy transformation will be through electricity systems, which are the focus of this paper. The continuing advances in renewable generation technologies, the increase in the use of 'smart' systems, and the further electrification of heat, transport, and cooking make electricity well placed to address current challenges. This is not to say that developments outside electricity will not have a significant impact on the wider energy system.

1.1 Smart electricity systems

Smart electricity systems are intelligent networks that integrate a range of generation, storage, and demand-side technologies to deliver electricity in the most cost-effective and resource-efficient way. They enable networks to manage variable outputs and match generation and consumption when renewable and distributed generation are connected. This provides opportunities for disruptive innovative solutions to deliver electricity to the consumer and accelerate the transition to low-carbon energy systems.

1.2 Disruptive innovations

'Disruptive innovations' are novel offerings that have the potential to impact how the current market operates. In some instances, they 'disrupt' the market by allowing alternative value propositions to be offered which satisfy emerging consumer needs (Rennie, 2018; Wilson, Pettifor, Cassar, Kerr, and Wilson, 2019). In other instances they disrupt the assets, relationships, and architecture of the system to benefit the suppliers and networks. Often, this is through a combination of technology and business model innovations. The technologies can be radical or incremental developments that can be used in novel ways to unlock commercial value through business model innovations. The disruption comes from the combination of technologies and business models operating within the market and regulatory environment. Influences are often from outside the sector: applications or approaches are brought into a new market to serve emerging needs.

A disruptive innovation addresses needs within a system that are not met by the existing market, and which existing players cannot easily switch to providing (Harvard Business Review, 2015). Often, these innovations start as niche offerings and over time become mainstream as adoption reduces the cost and the innovation displaces mainstream providers. However, due to their security and reliability demands, and the critical nature of the infrastructure, energy systems are highly regulated environments. This often makes it difficult for new entrants to access the markets with alternative approaches (Wilson, 2018).

Box 1: Key characteristics of disruptive innovations:

- **Consumers** – serving 'unmet' needs or different attributes that consumers value
- **Markets** – challenge what existing providers do or how the current market operates
- **Scale** – start small as a niche market
- **Impact** – disrupt how the market operates, by applying an alternative approach, or displace the market

1.3 Sub-Saharan Africa

In the coming decades, there is likely to be both population growth and an increasing per capita energy demand as standards of living increase, particularly in developing countries (BP, 2019). Indeed, much of the world's growth in energy demand to 2040 is expected to be in such regions, with a large proportion of this likely to be met by renewables (BP, 2019). The UN Sustainable Development Goals (SDGs) highlight the ongoing challenge facing the international community: to ensure access to affordable, reliable, sustainable, and modern energy for all (SDG 7), while taking urgent action to combat climate change and its impacts (SDG 13).

Access to electricity in developing economies is a major challenge, and the challenge is particularly acute in sub-Saharan Africa (The World Bank et.al., 2018). Today, market provision of electricity does not meet the needs of all consumers across large parts of the region – it is expensive, and the degree of access to electricity is highly variable across the region (The World Bank, 2016). Expanding the electricity grid in those countries with limited access would require significant investment and, in the short term, is unlikely to reach all end-users. The cost of energy would continue to be a barrier to access so there is a need for lower-cost, flexible options for communities.

1.4 Scope of this paper

This paper focuses on disruptive innovation in the electricity sector. It looks at each of the elements described above in closer detail to gain a clearer understanding of what the potential could be for low-carbon, smart energy solutions to 'disrupt' existing markets in sub-Saharan Africa. The next section examines three interlinked smart energy technologies which are likely to have a significant impact on electricity systems around the world, disrupting the status-quo. The paper concludes by exploring how such innovations may support a low-carbon transition in sub-Saharan Africa, and some of the key issues that will need to be addressed to help scale up their impact.

2. Disruptive technologies

The strong future requirement for low-carbon electricity generation is likely to include greater penetration of distributed, intermittent, non-dispatchable **renewables**. This presents challenges to the system, including balancing supply and demand, and giving consumers what they want at an acceptable cost. These challenges could be addressed through system management practices and business models, enabled by the presence of supply and demand **flexibility and energy storage**. To allow this flexible system to operate efficiently and effectively will require the communication technologies and data science approaches of **digitalisation**. In reality, the largest disruption from these three areas will occur when they are working in harmony, within an enabling market structure and regulatory framework. Within this market structure, there will be opportunities along the value chain to meet the new system needs.

2.1 Renewable energy generation

Over the coming decades, renewable electricity is highly likely to meet an increasing proportion of the world's energy demand. A key aspect that has made this a viable option is the significant cost reduction seen over the last few decades, and in recent years in particular. Between 2010 and 2017, the cost of an installed utility-scale solar photovoltaic (PV) system fell by nearly 80% (Fu, Feldman, and Margolis, 2018), resulting, in part, from significant investment in manufacturing methods and capacity. This investment was driven by increased demand due to feed-in tariffs in many Western countries, and the strategic industrial policies in China, which supported PV manufacturing expansion. Significant cost reductions have also been seen in on-shore and off-shore wind power.

Going forward, we will see more and more installations of solar PV plants and wind farms, more production of bio-energy, continued utilisation of hydroelectricity where the geography and environmental planning conditions allow, and more geothermal generation where possible. This will be key to achieving a reduction in the CO_2 released into the atmosphere, along with efficiency improvements and the utilisation of other low-carbon sources (e.g. nuclear power). This will lead to a reduction in the release of GHGs, and also of particulate matter.

Most electricity systems have developed based on the assumption that centrally owned, located, and operated generation assets offer the most efficient solution – one large coal power station costs less to build, operate, and maintain than a small one located on each street corner. The disruptive opportunity for renewable energy generation is that it lends itself to much greater distribution, both spatially and in terms of ownership. With regard to location, this could mean installation close to the demand, changing the requirements of the grid infrastructure, or generation for off-grid applications, where connection to the wider system is not feasible, desired, or cost-effective.

The cost reductions are forecast to continue, approaching cost parity with traditional gas and coal generation (Bloomberg New Energy Finance, 2018). However, the nature of that cost is different with renewable generation. For fossil fuel electricity, a significant proportion of the lifetime cost is in the fuel used, whereas for renewables (particularly solar, wind, and hydro) the costs are capital-intensive upfront. This means that renewable projects are not exposed to the uncertainties of global fuel markets and are not reliant on securing access to the fuel source, but it also means that the costs of financing the initial investment are significant. The unpredictability of future revenue streams add to this financing cost. However, due to the distributed nature of renewables, the risks (and opportunities) can be shared among a larger number of operators making individual and incremental investments, rather than large central investments.

The challenges of increasing the amount of renewable generation include the increased physical security required to protect the distributed valuable asset (particularly with solar, where there is significant resale value of individual panels), the increased land needed to site the installations, and the additional requirements placed on the rest of the energy system due to their intermittent, non-dispatchable nature. However, these additional requirements for services offer opportunities for the next disruptive technology discussed in this paper – flexibility and electricity storage.

2.2 Flexibility and electricity storage

Flexibility is a broad term used to cover the act of modifying the level and timing of electricity generation feeding into the network and of the demand drawing from it. This is done as a service to the system operator, to enable it to run smoothly, to strike a balance between supply and demand, and to maintain supply quality. As discussed in the previous section, balancing the system becomes more challenging as the amount of renewable generation increases. This is because renewable generation is intermittent and only produces electricity when the sun is shining and the wind is blowing (in the respective cases). In most of today's electricity systems, supply and demand are matched by utilising the flexibility of dispatchable power generation, which can be turned up or down whenever required (e.g. gas turbines), and by requesting that high demand users reduce demand temporarily.

The additional challenges placed on the system by the increase in renewable generation can expand the market for flexibility services and present opportunities for a more diverse selection of flexibility providers. However, this is a highly policy- and regulatory-driven market and institutional stability and clear market signals are required to encourage investment. As discussed in the next section, digitalisation increases the opportunities for consumers to provide flexibility to the system without disrupting the outcome they want – through smart appliances, for example. The increase in the types of consumer that could offer demand flexibility, and the different attributes of distributed storage, are likely to change the traditional approach.

Electricity storage can help with the provision of flexibility by acting as an electricity source when demand is higher than generation, and absorbing electricity when the demand is lower than generation. The options for electricity storage vary widely. Some, such as pumped hydroelectricity, are well established on many systems but require suitable topography, while others, such as batteries, are going through significant development, leading to performance increases and significant cost reduction.

Due to the value to the system operator of maintaining supply security, there are opportunities for disruptive innovation in flexibility services and technologies. Demand aggregation and virtual power plants are just two examples where this is already seen. In these cases, an organisation enters into agreements with a large number of small energy users (e.g. households) or generators (e.g. roof-top solar installation) to have some level of control over their system and aggregate their combined capacity to offer flexibility services to the network. However, this does mean that the responsibility for assets that support the system is distributed. It also increases system complexity and reliance on communications and data systems, as discussed in the next section of this report.

As with the increase in the amount of renewable generation on a system, additional, distributed flexibility services change the requirements placed on transmission, distribution, and communications systems. It also opens up further opportunities for local networks with a soft connection, or no connection to national transmission infrastructure, such as micro-grids.

The increase in the distribution of assets, spatially and in terms of ownership, and the variety of flexibility services that can be offered, also changes the needs of the market arrangements and the regulatory frameworks in which the system operates.

2.3 Digitalisation

Digitalisation is the use of digital information and data science within a system to optimise operations. It is a crucial driver that supports the new functions and markets required to transform the electricity system. This is sometimes referred to as smart grids. Digitalisation can be considered to encompass:

- the use of data and data techniques to support the efficient operation of the system;
- the deployment and use of sensing and actuation technologies and the associated communications infrastructure; and
- the use of automation and artificial intelligence to help make decisions about the design and operation of the system.

The aim of digitalisation of the electricity system is to increase overall system performance at least cost to those involved, through greater integration and communication between different assets and stakeholders. As discussed above, renewable energy and flexibility services change the demands placed on the electricity system, and for them to be successfully adopted widely, some level of digitalisation will be required.

The World Energy Council's 'Issues Monitor 2018' considers digitalisation to be a high impact, high uncertainty area, 'facilitating a rapid convergence of alternative technologies such as renewable energies, blockchain and data AI' (World Energy Council, 2018). Uncertainty exists around the extent to which digitalisation can be deployed and adopted in different systems, but some uptake is inevitable

The disruptive influence of digitalisation is that it enables greater penetration of renewable power generation, through the facilitation of flexibility services, and that it opens up opportunities for new markets, services, and business models to be established. For some markets, where the current infrastructure is not comprehensive, there is an opportunity to bypass the installation of non-digitalised grids, much like wired telephone systems were bypassed in much of the developing world and the leap was made straight to mobile telephony.

Digitalisation also offers the opportunity to have greater knowledge and visibility of the behaviour of users on the system. This can lead to greater billing and payment security, reduced likelihood of corruption, and higher investor confidence in future revenue security. Digitalisation can also reduce operating and transaction costs for companies, due to better data management and automation.

However, this disruption does come with challenges. There is increased system complexity, with requirements for extensive communications and computation infrastructure, where interoperability must be considered (device, data, physical, commercial, etc.), alongside the power carrying infrastructure (Energy Systems Catapult, 2018). There are also issues around the security of the data systems to ensure consumers' data privacy, clarity of data ownership, and the security of the increased number of access points on the system, which could be targets for unauthorised interference (cyber threats).

2.4 Other innovations

The three areas discussed above by no means cover all the disruptive influences that the energy industry and electricity sector will experience. Other examples which may have significant impact are the electrification and automation of transport (bringing opportunities for smart charging and vehicle-to-grid (V2G) services, for example); the connection of the just under 1 billion people with no access to electricity (more than 95% of whom are in countries in sub-Saharan Africa and developing Asia); and the growing entrepreneurial activity within energy-related services and business models. However, these will also rely on the further deployment of renewable generation technologies, the resulting increase in market potential for flexibility services and energy storage, and underlying digitalisation enabling operation of the system.

It is also likely that developments in other sectors could have a disruptive influence on energy markets. For example, innovative financial technologies and secure, universal communication systems could change the way consumers interact with their electricity supplier.

Box 2: Case study – Heat-as-a-service – Bristol Energy

Bristol Energy has become the first energy supplier in the UK to trial selling 'heat-as-a-service' (HaaS), rather than kilowatt hours (kWh).

Currently, energy suppliers in the UK can only sell energy to customers in strict units known as kWh., but through a government-backed trial run by Energy Systems Catapult, Bristol Energy is offering households the chance to buy a 'Heat Plan' tailored to their individual home and lifestyle.

Heat Plans provide consumers with room-by-room, hour-by-hour control over their heating. Using data collected via a smart heating control system, the energy provider can calculate a fixed monthly cost that is bespoke to the triallist's home and lifestyle, and that does not fluctuate with the weather.

This approach is designed to give people greater control over comfort and cost. Crucially, it also:

- provides a commercial incentive for energy providers to deliver comfort using less energy and carbon;
- an opportunity for energy providers to differentiate themselves in a market; and
- could potentially create a route-to-market for low-carbon technology.

This is an example of a case where digitalisation has created disruptive new market opportunities and could lead to energy service providers providing flexibility services to the wider system. In this case, the heat is provided by individual natural gas boilers in homes. However, one of the aims of the trial is to show that the source of heat does not matter. The supplier is not selling the consumer 'gas for their boiler' or 'electricity for their heat pump', they are providing the consumer with a level of service under a contracted 'Heat Plan'. This could equally be a 'Cooling Plan' – cooling-as-a-service (CaaS).

3. Opportunities and challenges for disruptive smart electricity technologies in sub-Saharan Africa

Approximately 1 billion people live in sub-Saharan Africa today, twice as many as in 1990 (United Nations, 2017). This population has a low overall energy demand per capita and a *very* low electricity demand per capita. This is, in part, due to the significant numbers of people without access to an electricity connection. In the whole of sub-Saharan Africa, in 2016 only 43% of the population had an electricity connection, although this is increasing, as in 2000 it stood at 23% (International Energy Agency, 2017). The coverage, however, is highly variable between countries and the nature of energy supply and institutional factors creates a mosaic of challenges and opportunities across region. The level of electrification will have to increase over the coming decades, as efforts are made to achieve the UN SDGs, as discussed above. This, along with the growing population – projected to double again by 2050 (United Nations, 2017) – will lead to a significant increase in energy demand in the region.

Today, a large proportion of the total energy demand of sub-Saharan Africa is met by the burning of kerosene for lighting, biomass (primarily wood) for domestic heating and cooking, and oil for transportation. In 2014, 60% of the total energy demand was met by biomass and the total electricity demand for the region was less than that of France in the same year (World Energy Council, 2017; RTE, 2014).

Within the electricity sector, generation is dominated by fossil fuels, with oil, gas and coal generation satisfying 70% of the region's electricity demand in 2014 (World Energy Council, 2017). The one renewable technology which has made an impact on the system is hydroelectricity, which generated nearly a quarter of the electricity in 2014. However, there is huge renewable electricity potential in sub-Saharan Africa: wind, geothermal, expansion of the current hydro capacity, and, in particular, solar are all seen as playing a significant part in the region's future electricity system.

3.1 Signs of change

In recent years there has been a growing trend towards greater investment in and adoption of other sources of renewable electricity and infrastructure. The World Bank-backed Nigeria Electrification Project aims to increase access to electricity in Nigeria by facilitating the development of solar-hybrid mini-grids and stand-alone solar systems for homes and small businesses. It also seeks to provide affordable, reliable, and sustainable power to universities and teaching hospitals, and to promote rural electrification (The World Bank, 2018). Meanwhile, the African Development Bank is supporting the Kenyan Last-Mile Connectivity Programme (LMCP), which aims to extend the low-voltage electricity network to connect an additional 2.5 million Kenyans to the power grid over its two phases (African Development Bank Group, 2014).

Kenya is also collaborating with financial institutions to prepare multiple sites for renewable energy production. The Lake Turkana Wind Power Project, for example, is the biggest wind farm in Africa and the single largest private investment in Kenyan history. The project will help address the existing energy gap in the country while saving significant GHG emissions compared to the fossil fuel-based alternatives.

In many countries around the world, the introduction of energy auctions, or competitive tenders, has driven the development of renewable energy generation markets and reduced costs. In sub-Saharan Africa, more than 18 countries are developing or have implemented energy auction schemes to procure renewable energy. Of these, the South African scheme is by far the biggest.

At the smaller scale, the number of small solar installations and micro-grids has increased recently. For example, in Kenya and Tanzania multiple international companies have started offering solar pay-as-you-go (PAYG) systems to those not connected to the electricity grid (World Resource Institute, 2016). Both the energy company and the consumer benefit from the PAYG approach, with simplification and cost reduction of the payment collection process and removal of the need for large upfront capital expenditure by users. In addition, this could be seen as a step towards an energy-as-a-service (EaaS) offering, with some companies advertising and providing lighting and mobile phone charging services, rather than promoting the panels or the energy.

Box 3: Case study – M-KOPA Solar

M-KOPA is a Kenyan company providing innovative solar power solutions in Kenya, Tanzania, and Uganda that help low-income consumers access electricity. They have developed a proprietary, patented technology platform that combines mobile communications and mobile phone payments capabilities to enable the financing of the solar power equipment. Customers buy the solar home system on a payment plan, with an initial deposit that is followed by daily payments through their mobile phones for up to one year. As at January 2018, M-KOPA had connected over 600,000 homes to affordable solar power. The estimates from the M-KOPA solar programme show that current customers will save up to US$450 million over the next four years on energy costs and enjoy 75 million kerosene-free months of lighting.

3.2 Challenges

Despite the huge opportunities and signs of development in the electricity systems of sub-Saharan Africa, significant institutional challenges remain. A recent project looking at the progress made by Kenya's LMCP identified multiple issues (Miguel, 2018). At its outset, the LMCP aimed to provide almost universal electricity coverage by 2020. However, issues of transparency and accountability concerning the independent construction firms delivering the new connections (including work quality, reliability, delays, invoice discrepancies, and reports of communities asked to pay bribes, etc), and the links between provision in a local area and its political affiliation, have brought some of the scheme's proposed benefits into question.

A recent institutional diagnostic of the electricity sector in Tanzania found that underinvestment in the sector since the 1990s has stunted its evolution and continues to do so today (Godinho and Eberhard, 2018). This, combined with undue political influence in planning and procurement, leading to large-scale corruption, has led to persistent supply insecurity. Load-shedding is now an everyday occurrence in Tanzania, and can last up to 18 hours per day.

Today, 71% of sub-Saharan African countries have a vertically integrated utility structure where all services within the system are bundled together and fall under the remit of one entity (Attia and Shirley, 2017). The bundled nature removes the efficiency improvement, and system optimisation advantages seen in liberalised markets. Many of the systems are also under direct state control and have a long history of poorly maintained and weak transmission and distribution infrastructure, with limited reach. This also leads to difficulties in financing improvements due to regulatory and administrative hurdles, high risks, and often a lack of scale.

As well as the institutional challenges, the changing energy system must also deal with the issues presented by the intermittent nature of renewable electricity production and the changing nature of the demand from consumers. Managing the system operation complexities of the future can be eased by the use of flexibility and the data and optimisation aspects of digitalisation. For some markets, where the current infrastructure is not comprehensive, there is an opportunity to bypass the installation of non-digitalised grids, much like wired telephone systems were bypassed in much of the developing world and the leap was made straight to mobile telephony. Further cost and efficiency benefits may be available as a result of utilising the interaction between energy vectors. This opens up more options for flexibility and new business models through broader service provision. For example, through bundling with other sectors – telecoms, TV, mobility, retail, etc.

3.3 Conclusion

There is huge potential in sub-Saharan Africa for smart, clean energy technologies and business model innovations. These are already starting to offer alternative value propositions to consumers and have the potential to impact how the current market operates. How consumers respond to the offerings (the consumer 'pull' dynamic) ,and the scale and pace of adoption across the region, will be an interesting area for research, given the uncertainty of future demand characteristics and the potential expansion of a much wider range of services.

Investment and financing costs of clean energy technologies and infrastructure requirements remain key challenges. Investment risks are considered higher in sub-Saharan Africa, increasing the cost of finance. Local policy commitments, regulatory reform, and administrative improvements will be required if this risk is to be reduced. Reduced risk, together with mechanisms for greater transparency (enabled by digitalisation), could help sub-Saharan African countries attract investment and form international partnerships. It will also be vital for countries to support nascent indigenous technologies and industries to develop and expand local supply chains and jobs. However, there is significant variability resource availability, security, electricity access, and political and institutional stability across the region.

While external financing and global initiatives provide valuable assistance, localised policy reform and dedicated governance will be key for achieving long-term success in the region. The governments concerned must demonstrate a greater determination to improve the livelihoods of their citizens and commit to doing so through policy and regulation to enable a low-carbon transformation of the energy system. Some positive steps have been taken, which the region can benefit and learn from over the coming years. If more African nations rise to the challenge, the opportunities for the future will be enormous.

Bibliography

African Development Bank Group (2014) 'Kenya – Last Mile Connectivity Project'. Retrieved from https://www.afdb.org/en/projects-and-operations/project-portfolio/p-ke-fa0-010/

Arcanjo, M. (2018) 'Revolutionising Renewables in Sub-Saharan Africa'. Climate Institute.

Attia, B., and Shirley, R. (2017) 'How Deregulation Could Improve Reliability for Cash-Strapped African Utilities'. Green Tech Media.

Bloomberg New Energy Finance (2018) 'New Energy Outlook 2018'.

BP (2019) 'Energy Outlook 2019'.

Castellano, A., Kendall, A., Nikomarov, M., and Swemmer, T. (2015) 'Brighter Africa: The growth potential of the sub-Saharan electricity sector'. McKinsey & Company.

Energy Systems Catapult (2018) 'An Introduction to Interoperability in the Energy Sector'. Retrieved from https://es.catapult.org.uk/news/an-introduction-to-interoperability-in-the-energy-sector/

Fu, R., Feldman, D., and Margolis, R. (2018) 'U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018'. National Renewable Energy Laboratory.

GE Power (2018) 'White paper on Digitization of Energy Transmission and Distribution in Africa'.

Godinho, C., and Eberhard, A. (2018) 'Tanzania Institutional Diagnostic - Chapter 7: Power Sector Reform and Regulation in Tanzania'. Economic Development & Institutions.

Harvard Business Review (2015) 'Tesla's Not as Disruptive as You Might Think'. Retrieved from https://hbr.org/2015/05/teslas-not-as-disruptive-as-you-might-think.

International Energy Agency (2014) 'World Energy Outlook 2014 Factsheet - Africa Energy Outlook'.

International Energy Agency (2017) 'Energy Access Outlook 2017'.

International Renewable Energy Agency (2018) 'Renewable energy auctions: Cases From Sub-Saharan Africa'.

Miguel, E. (2018) 'The Political Economy and Governance of Rural Electrification'. Economic Development and Institutions Research Link-up.

Rennie, M. (2018) 'How Enabling and Disruptive Technologies are Impacting the Electricity System'. EY. Retrieved from https://www.ey.com/en_gl/digital/how-enabling-and-disruptive-technologies-are-impacting-the-elect

Réseau de transport d'électricité (RTE) (2014) '2014 Annual Electricity Report'.

The World Bank (2016) *Data Bank: Access to electricity (% of population).* Retrieved from https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=ZG

The World Bank (2018) 'Nigeria Electrification Project'. Retrieved from http://projects.worldbank.org/P161885/?lang=en&tab=overview

The World Bank *et al*. (2018) 'Tracking SDG7: The Energy Progress Report 2018'.

United Nations (2017) 'World Population Prospects: 2017 Revision'.

Wilson, C. (2018) 'Disruptive Low-Carbon Innovations'. *Energy Research & Social Science* 37, pp. 216–223. Retrieved from https://doi.org/10.1016/j.erss.2017.10.053

Wilson, C., Pettifor, H., Cassar, E., Kerr, L., and Wilson, M. (2019) 'The potential contribution of disruptive low-carbon innovations to 1.5 °C climate mitigation'. *Energy Efficiency* 12, p. 423. Retrieved from https://doi.org/10.1007/s12053-018-9679-8

World Energy Council (2017) 'World Energy Scenarios 2017 – Regional Perspective for Sub-Saharan Africa'.

World Energy Council (2018) 'World Energy Issues Monitor 2018 | Perspectives on the Grand Energy Transition'.

World Resource Institute (2016) 'Stimulating Pay-As-You-Go Energy Access in Kenya and Tanzania: The Role of Development Finance'.

About the authors

Stuart McKinnon has worked in the energy sector for over 10 years, leading technology development teams in an energy start-up and an engineering consultancy, and carrying out commercial and technical evaluations of emerging innovations. In his current role in the strategy team at the Energy Systems Catapult he studies the impact of technology, social, policy, market and commercial developments on the future of the energy system and on the work of the organisation.

Rachel Mulhall is a market analyst at the Energy Systems Catapult. Her expertise is in energy retail markets, local economic development, and competitiveness. Rachel has contributed to local and national government evidence reviews, and has published research in these fields.

Emma Owen is International Research and Development Manager at the Energy Systems Catapult, working to identify UK innovation opportunities for overseas energy exports. Emma brings a multi-layered approach to energy and climate change issues through her experience of working across sectors (public, private, and non-profit) at international, national and regional levels, on themes ranging from sustainable transport and energy policy through to innovation and technology commercialisation.

Front cover image: Hongqi Zhang / **Alamy Stock Photo**