MICRO-GRIDS

EMPOWERING COMMUNITIES AND ENABLING TRANSFORMATION IN AFRICA

African Union

NEPAD
TRANSFORMING AFRICA

About the AU and NEPAD

The African Union (AU)

The African Union (AU) is a continental body consisting of all 55 countries on the African continent. It was established on 26th May 2001 in Addis Ababa, Ethiopia, and launched on 9th July 2002 in South Africa,[6] with the aim of replacing the Organisation of African Unity (OAU). The most important decisions of the AU are made by the Assembly of the African Union, a semi-annual meeting of the Heads of State and Government of its member states. The AU's secretariat, the African Union Commission, is based in Addis Ababa, Ethiopia.

The AU was established following the 9th September 1999 Sirte Declaration of the Heads of State and Governments of the Organisation of the African Unity (OAU). The AU is based on a common vision of a united and strong Africa and on the need to build a partnership between governments and all segments of civil society, in particular, women, the youth and the private sector, in order to strengthen solidarity and cohesion amongst the peoples of Africa. As a continental organization, it focuses on the promotion of peace, security and stability. The development work of the AU is guided by the AU Agenda 2063, which is a 50-year plan to harness Africa's comparative advantage to deliver on the vision of "The Africa We Want".

African Union

NEPAD
TRANSFORMING AFRICA

The New Partnership for Africa's Development (NEPAD)

Created by the African Union, New Partnership for Africa's Development (NEPAD) is a strategic framework for pan-African socio-economic development. NEPAD is spearheaded by African leaders to address critical challenges facing the continent, including poverty, development and Africa's international marginalization. NEPAD provides unique opportunities for African countries to take full control of their development agendas, to work more closely together and to cooperate more effectively with international partners.

NEPAD is coordinated and facilitated by the NEPAD Planning and Coordinating Agency (NEPAD Agency) which was established in February 2010 as an outcome of the integration of NEPAD into the AU's structures and processes. The NEPAD Agency manages a number of programmes and projects in four investment portfolios, namely Natural Resources Governance, Youth and Skills Development, Regional Integration, Infrastructure and Trade, and Industrialization, Science, Technology and Innovation.

Members of the High-Level African Panel on Emerging Technologies

Co-chairs

Calestous Juma, John F. Kennedy School of Government, Harvard University, USA (Deceased)

Yaye Kène Gassama, Université Cheikh Anta Diop de Dakar, Senegal

Panel Members

Abdallah Daar, University of Toronto, Canada

Berhanu M. Abegaz, African Academy of Sciences, Ethiopia

Francine Ntoumi, Fondation Congolaise pour la Recherche Médicale, Congo-Brazzaville

Karim Maredia, Michigan State University (MSU), East Lansing, Michigan, USA

Oye Ibidapo-Obe, Federal University Ndufu Alike, Ikwo (FUNAI), Nigeria

Rachel Chikwamba, Council for Scientific and Industrial Research (CSIR), South Africa

Roseanne Diab, Academy of Science of South Africa (ASSAf), South Africa

Shireen Assem, the Agricultural Genetic Engineering and Biotechnology Research Institute (AGERI), Egypt

Secretariat

Aggrey Ambali (Coordinator) – NEPAD Agency

Diran Makinde – NEPAD Agency

Towela Nyirenda-Jere – NEPAD Agency

Jeremy Ouedraogo – NEPAD Agency

Hlazo Mkandawire – NEPAD Agency

Hudu Mogtari – NEPAD Agency

Justina Dugbazah – NEPAD Agency

Margaret Mahlomuza – NEPAD Agency

Barbara Glover – NEPAD Agency

Mahama Ouedraogo – African Union Commission

Monica Idinoba – Africa Union Commission

Hambani Masheleni – Africa Union Commission

Kate Bauer – Harvard University

Research

Towela Nyirenda-Jere (NEPAD Agency) **Titus Oluwasuji Ajewole** (Osun State University, Nigeria), **Joseph Mutale** (University of Manchester), **Peter Dauenhauer** (University of Seattle), **Aggrey Ambali** (NEPAD Agency)

Acknowledgements

We thank the various experts identified by the African Union High-Level Panel, who made contributions and comments on earlier versions of this report. We thank Sir Professor Brian Heap and Dr John Holmes of Cambridge University for providing feedback on earlier drafts of the report.

Table of Contents

Figures

Tables

Acronyms

AC	Alternating Current
AfDB	African Development Bank
AFREC	African Energy Commission
AFSEC	African Electro-technical Standardization Commission
AFUR	African Forum for Utility Regulators
AMU	Arab Maghreb Union
APUA	African Power Utilities Association
AU	African Union
AUC	African Union Commission
AWAUR	Association of West African Utility Regulators
CEN-SAD	Community of Sahel-Saharan States
COMESA	Common Market for Eastern and Southern Africa
COMEST	World Commission on the Ethics of Scientific Knowledge and Technology
DC	Direct Current
DESCO	Distributed Energy Service Company
DGR	Distributed Generation Resources
DSM	Demand Side Management
EAC	East African Community
EACREEE	East Africa Community Centre for Renewable Energy and Energy Efficiency
EAPP	East African Power Pool
ECCAS	Economic Community of Central African States
ECOWAS	Economic Community of West African States
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EE	Energy Efficiency

EREA	Energy Regulators Association of East Africa
ERERA	ECOWAS Regional Electricity Regulatory Authority
ESI	Electricity Supply Industry
ESMAP	Energy Sector Management Assistance Programme
EUEI PDF	EU Energy Initiative Partnership Dialogue Facility
GPRS	Generalised Packet Radio System
GSM	Global System for Mobile
GW	Gigawatt
ICT	Information and Communication Technology
IEA	International Energy Agency
IGAD	Inter-governmental Authority on Development
IP	Intellectual Property
IPP	Independent Power Producer
IRB	Independent Regulatory Board of EAPP
IRENA	The International Renewable Energy Agency
KW	Kilowatt
LED	Light Emitting Diode
M&E	Monitoring and Evaluation
MEP	Minimum Energy Performance
MW	Megawatt
NEPAD	New Partnership for Africa's Development
ODA	Overseas Development Assistance
PIDA	Programme for Infrastructure Development in Africa
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PPPPs	Public-Private-People Partnerships

PV	Photovoltaic
QoS	Quality of Service
RAERESA	Regional Association of Energy Regulators for Eastern and Southern Africa
RCREEE	Regional Centre for Renewable Energy and Energy Efficiency
RE	Renewable Energy
REA	Rural Electrification Agency
REC	Regional Economic Community
REFITs	Renewable Energy Feed – In Tariffs
RERA	Regional Electricity Regulators Association
SACREEE	SADC Centre for Renewable Energy and Energy Efficiency
SADC	Southern Africa Development Community
SDGs	Sustainable Development Goals
SE4All	Sustainable Energy for All
SMME	Small, Medium and Micro-sized Enterprises
SREP	Scaling Up Renewable Energy Program
UMA	Union Maghreb-Arab
UN	United Nations
UNECA	United Nations Economic Commission for Africa
UNESCO	United Nations Education and Science Commission
UNICEF	United Nations International Children's Fund
UNIDO	United Nations Industrial Development Organisation
USAID	United States Agency for International Development
WHO	World Health Organisation
WIPO	World Intellectual Property Organisation

Executive Summary

The challenge of access to energy has been recognised at the level of the UN and the African Union through the Sustainable Development Goals (SDGs) and the AU Agenda 2063 respectively. Goal 7 of the SDGs aims at achieving universal access to affordable, reliable, sustainable and modern energy by 2030, while Agenda 2063 has targets for an increase of 50% increase in electricity generation, 50% distribution and 70% of Africans having access to electricity by 2023. The growth of Africa's economies, which is underpinned by rapid urbanisation and industrialisation requires substantive amounts of energy to sustain and maintain an upward trajectory. Unfortunately, Africa has an enormous energy deficit. In sub-Saharan Africa close to 70% of the population does not have access to electricity and only 7 countries have electrification rates higher than 50%, the majority being under 20%. It should be noted that North Africa is the exception as access to energy is well above 95% in most of the region. The total generation capacity of sub-Saharan Africa is less than 100GW and close to 25% of this is unavailable due to aging equipment and distribution losses.

An increasing population, projected to reach 2 billion by 2040, is also contributing to the demand for energy. Currently 70 to 80% of Africa's population is rural and even in the face of urbanisation a significant percentage will remain rural in the next two decades. Supporting the transformation of rural economies necessitates not only access to energy but also affordable access. Low electrification rates prevail due to the challenges associated with providing energy in rural and remote areas. Meanwhile, affordable access to energy for productive usage is a prerequisite for the transformation of rural communities and for industrialisation in both urban and rural areas. Massive development of the electricity supply infrastructure beyond current levels is thus required to meet the demands of Africa's rapidly growing population and universal access targets.

While no single definition of micro-grids exist, micro-grids have as essential features the generation, distribution and supply of energy to localised loads with limited generation capacities and geographic coverage. Micro-grids are not a new phenomenon in that early development of the electricity supply system was in fact founded on unconnected generation and transmission systems. Efficiencies and economies of scale resulted in their interconnection into the large complex grids that we know today.

The efficiencies and economies of scale of inter-connected grids notwithstanding, there are several imperatives not only in Africa but globally as well, that are driving the move towards micro-grids. One is the emergence of independent power producers (IPPs) as opposed to incumbent national grid owners. IPPs are privately owned entities that produce power which is either fed into the main grid or supplied directly to consumers. A second reason for micro-grids is the move towards sustainable energy from renewable sources such as micro-hydro, solar and wind for use in localised communities such as business parks, universities and residential areas. In some cases so-called "grid-independence" is fuelling the development of micro-grids.

While the under-development of Africa's grid infrastructure contributes to an energy deficit, it provides an opportunity for Africa to re-engineer its electricity supply system, developing an architecture that integrates both on- and off-grid solutions. The cost implications of developing the traditional power grid based on large scale central generation favour off-grid micro-grids as a cost effective path to providing electricity access to rural and remote communities in the short term. Even where micro-grids may not make economic sense, rural electrification strategies may opt to implement micro-grids on the basis of providing energy access to stimulate productive usage and rural industrialisation.

While acknowledging that under current rates of energy infrastructure investment and deployment, universal access targets will not be met by 2030, off-grid solutions are expected to contribute to more than 50% of the electricity generation capacity required for universal access. As such, the last few years since the adoption of the SDGs have seen significant efforts being placed on the development and deployment of micro-grids and their associated technologies.

There is extensive literature on the deployment of micro-grids in Africa, showing that significant time and effort are being applied to solving Africa's energy challenges, particularly in rural or remote areas. An analysis of more than 40 initiatives suggests that wide-scale deployment of micro-grid technology in Africa will require technical and financial support that is complemented by policy advisory services, multi-sectorial stakeholder engagement and consumer education and awareness. Aspects that merit attention include integration of micro-grids in regional strategies, sustainable operational models and engendering productive use. Overall, the analysis affirms the role that micro-grids have to play in increasing access to energy in Africa, their potential to transform communities, and the creation of opportunities for research and innovation.

Research and innovation opportunities can be found in all the various sub-components of micro-grids– generation (energy sources), storage, distribution system, control system and the loads, as well as in associated technologies such as ICTs. Research is required to understand the interaction between the different combinations of energy and storage options. This should go together with research in new battery technologies and alternative storage options such as flywheels and capacitors. Research is also needed on efficient means of connecting micro-grids with larger centralised grids and on rapidly configurable grids that can be easily deployed in rural and remote areas. In addition to dedicated research facilities, living laboratories should be used to enable research and innovation in real-life use-cases.

The combination of multiple energy and storage sources into a single micro-grid configuration to maximise the availability of energy requires research to understand the interaction between these different options and combinations. Research could focus on feeder automation, the use of advanced controls to manage outages and predictive and corrective measures of compensating for transient system instability and general effects on the stability of energy supplied. Currently, fully-autonomous micro-grids are easier to implement and the most common in Africa. However research should focus on efficient means of connecting micro-grid with larger centralized grids so as to provide higher levels of reliability.

In current micro-grid deployments, energy storage can account for as much as 40% of the installation cost. Thus research in battery storage technology should focus on achieving higher energy density (more power) for longer durations with decreasing costs. In addition to new battery technologies, research is also required on alternatives to battery storage such as flywheels and super-capacitors. While e-waste is an undesirable attribute of technology deployment, the repurposing and recycling of lead-acid batteries is another area of research associated with micro-grid deployment. Through repurposing, batteries that have reached the end of useful life for micro-grids can be reconditioned and used in other ways.

Borrowing from the use of autonomous driverless electric vehicles (EVs) for emergency and disaster applications, research can be conducted into using the same principles to design rapidly configurable mobile micro-grids. These could be deployed in remote areas where instead of setting up dedicated infrastructure, energy could be transported by these mobile grids from community micro-grids to the points of need or usage.

Alongside research, prevailing conditions of geography, demographics and limited infrastructure provide a fertile environment for innovative solutions and approaches through living laboratories which enable concurrent research and innovation by integrating investigation and experimentation in real life use cases. While dedicated research facilities are ideal, living laboratories can promote rapid adaptation and prototyping, and this is particularly relevant for Africa where in most cases, technologies are imported and may need to be adapted to the operating environment. Living laboratories can work to advance DC micro-grid technology (solar panels, LED lights, DC appliances) which is of particular interest for Africa, since for most rural and remote areas off-grid implementation will hinge on DC technology.

Elements of micro-grid deployment such as the geographical span of the area to be serviced, the type of end-user load the grid can supply, the means of recording and metering the usage of energy, billing and payment systems, all have implications on the cost to deploy and maintain micro-grids. Therefore, these require on-going research to develop sustainable business models. Micro-grid deployment is an opportunity for Africa to develop a critical mass of scientists, engineers and technicians around the technology. A major capacity building and investment effort will thus be required to develop the cadre of skilled staff within Africa to design, deploy and maintain micro-grids at the required pace and scale to achieve transformative impact. Through these capacity and skills development efforts, Africa could invest in its growing youth population, and an investment in such a demographic group could pay dividends.

Regional energy strategies, complemented by national (rural) electrification strategies will set the tone for micro-grid development. Associated policy, legal and regulatory environment determines the extent to which micro-grids can be deployed and how this can be achieved using a mixture of public and private funds. Strategic choices have to be made as to whether micro-grids will be wholly funded by government, the private sector, utilities, communities themselves or through different kinds of partnerships. For rural areas, community ownership is an option if the community is empowered to manage the micro-grid sustainably. Policies are needed to address the investment climate and public-private partnerships stimulate holistic and robust business models and engender productive uses.

A well-developed legal and regulatory framework is essential and this is an area that is still not yet mature in Africa where regulatory efforts struggle to keep pace with technological and other developments. Thus, it is important that independent regulatory authorities are established, and take responsibility for defining licensing and registration regimes for independent power producers, streamlining procedures, as well as developing and enforcing standards for critical components such as solar panels, inverters, charge controllers and batteries.

Pro-poor approaches should also encourage productive use of micro-grids by the communities. This is effective when a multi-sectorial approach to planning and implementation of rural electrification and micro-grid programmes is undertaken. Policies should also ensure that requirements of women and youth are mainstreamed in the deployment of mini-grids. This empowers them not only with access to energy, but also with opportunities to benefit from entrepreneurship and productive use of the supplied electricity. Taking into account the strategy and policy choices and the existing experiences with micro-grid deployment, the report ends with recommendations from the AU High Level Panel for the wider deployment of micro-grids.

Micro-grids are the cornerstone of the sustainable, resilient power systems of the future. Just as witnessed in the mobile phone revolution, which completely democratised access to communication, it is expected that energy access might experience a similar revolution that will allow easy and safe access to energy for all. Micro-grids present an economically feasible opportunity to accelerate access to electricity for remote communities on the vast continent of Africa. Key areas to be considered include capacity-building, enabling/supporting infrastructure, regulatory strengthening, research and development and stakeholder engagement.

The Panel recommends that the AU, RECs, Member States and their partners should consider the following:

- Micro-grid implementation should be adapted and contextualised for Africa, taking into account factors such as site selection, the expected number of connections per site, the demand and willingness to pay and the expected return per connection. The Panel further recommends that contextualisation should be based on the prevailing natural resources to determine optimal selection of the underlying energy source (solar, wind, biomass or thermal).

- Skills and capacities for addressing under-served communities and the “informal sector” to support micro-grid implementation must be developed. This would mitigate against cases cited in some countries where micro-grid installations have suffered from not being properly operated or maintained, leaving communities not able to derive the intended benefits.

- Harmonised regulatory frameworks for micro-grid development which would focus, among other things, on investment laws and PPPs, sustainable tariff structures and cross-border interconnection must be put in place. The Panel further recommends the development of smart regulation leveraging on emerging trends in the use of ICTs.

- Micro-grid implementation should be based on multi-sectorial collaboration since interventions in agriculture, health, education, water and sanitation, social welfare and other sectors all have potential implications for energy projects.

- To stimulate bankability of micro-grid projects, a robust framework of incentives should be developed to stimulate private investment. The Panel further recommends the decentralisation of regulatory and support processes to local government level to enable mobilisation of domestic resources and faster, tailored responses to micro-grid deployment in under-served communities.

- Projects should aim to increase women’s participation in the energy sector through procurement allocation policies and by promoting employment of women in technical aspects of operation and maintenance. Projects should also encourage women to participate actively as business leaders and entrepreneurs, providing value-added productive services including producing and distributing new energy technologies and services. The panel therefore, recommends the promotion and strengthening of participation along entire micro-grid value chain by women and the youth.

- Lastly, higher education and research institutions should be supported to start implementing programmes that focus on renewable energy, micro-grids and associated generation, storage and distribution technologies. This should go together with the strengthening of intellectual property regimes, as well as increased awareness of how to license and use existing IP.

Significant innovation is being witnessed in the delivery of micro-grids in Africa. With the right incentives, legal and regulatory environment, Africa has the capacity to develop the required technical solutions to provide cost-effective electricity in rural communities, using micro-grid technologies. Up-scaling of the solutions will thrive in areas where the legal and regulatory framework is well developed and rigorously enforced. This is an area that needs to be looked at in Africa where current legal and regulatory efforts are not keeping pace with development. The availability of standards that allow for interoperability of systems will also be critical to encourage careful scaling up as demand grows.

1

Introduction

Despite the availability of reliable and affordable electrical energy being a critical factor in development, Africa remains the least electrified continent with close to 70% of the population not having access to electricity [91]. In addition to the deficit of access, Africa also suffers from a general deficit of power even for those that have access to electricity. The average person in sub-Saharan Africa (excluding South Africa) consumes around 190KWh of electricity, compared to 13000KWh in America [8]. The power deficit can be attributed to several factors, including the lack of reliable power supply and the high cost of electricity. Factoring in 2030 targets for universal access to energy and considering Africa's rapidly growing population -- projected to double from the current circa 1.2 billion to 2.5 by 2050 -- calls for massive development of the electricity supply infrastructure [91].

With a population that is predominantly rural, the health and socio-economic impacts of lack of access to clean energy become more magnified in Africa. Access to education, health and other services in rural areas is affected by the lack of access to energy. With a sustainable energy supply and an educated workforce, other challenges such as access to clean water, food, healthcare and shelter have a better chance of being solved.

In addition to the improved welfare and well-being, access to energy is essential to realise Africa's aspirations for industrialisation and this should take into account both urban and rural opportunities for industrialisation [89][97]. In rural areas, access to energy can stimulate and support productive use of energy for activities such as irrigation and agro-processing, to mention two examples.

Most electricity in Africa is supplied by state-owned enterprises that supply electricity through centrally managed national grids. The Africa Progress Panel, in its 2017 report, acknowledges that scaling up national and regional grids through mega-projects such as large dams and power pools, as envisaged by the Programme for Infrastructure Development in Africa (PIDA). This is essential but highlights the concern that this approach is slow and expensive and therefore, not viable as an immediate solution for the 620 million Africans without access to electricity [11]. The solution is thus to consider smaller, decentralised means of providing energy through micro-grids. These could consist of localised electric power supply systems that combine a cluster of loads and different kinds of distributed generation resources (DGR) to operate as a single, controllable system providing power to a local area.

The International Renewable Energy Agency (IRENA) classifies a "micro-grid" as an energy generation and supply system with maximum capacity of 100 kilo-Watts having capabilities of managing local energy supply as shown in Table 1 [56]. "Mini-grids" are similar but larger, more complex systems with the ability to sometimes provide power transmission and an interconnection to the main grid.

Table 1: IRENA Classification of Nano-/Micro-/ Mini- Grids[1]

	Maximum Capacity (KW)	Capability	Complexity
Stand-alone systems	0.1		
Pico-grid	1	Single controller	
Nano-grid	5	Single voltage Single price Controllers negotiate with other across gateways to buy or sell power	Both grid-tied and remote systems Preference for DC systems Typically serving single building or single load Single administrator
Micro-grid	100	Manage local energy supply and demand Provide variety of voltages Provide variety of quality and reliability options Optimise multiple-output energy systems	Incorporate generation Varying pricing possible
Mini-grid	100 000	Local generation satisfying local demand Transmission limited to 11 kV	Interconnected customers

Micro-grids can operate either in parallel to (on-grid) or "islanded" (off-grid) from the existing utility power grid [18]. In order for the current pace of electrification to meet universal access targets, off-grid solutions will need to supply 50 to 60% of the additional generation needed. Therefore, for Africa over the next decade, the focus should be on autonomous or "off-grid" systems. These can be deployed in the most remote areas that will remain unreached by grid extension for some years to come [11][85]. The deployment of off-grid systems should not take the focus away from grid expansion or centralised large-scale power generation. These are

1 It should be noted that in the literature, the term micro-grids is more common and can also be used to refer to mini-grids as per the IRENA definition

still needed to meet the needs of urbanisation and industrialisation. Off-grid systems should be seen as complementary efforts to address the particular aspect of rural electrification, providing access where grid-expansion is not feasible in the short-term.

Africa has massive potential for renewable energy through solar, hydro, wind and geo-thermal sources. Yet currently renewable energy represents only 17% of power generation in Africa, largely from hydro resources [53]. In deploying micro-grids, Africa stands to benefit from its abundant renewable energy sources as opposed to relying on non-renewable sources like fossil fuels or nuclear energy. As such, investments must be made in renewable off-grid and mini-grid solutions which are cheaper and quicker to deploy. The AU Agenda 2063 has a goal of reaching the target of providing access to 315 million people by 2040. However, with only 30% of these currently connected to national grids, there is need for innovation not only in technology but also in approach and in the uptake of the technology.

This report presents different aspects of micro-grids as an emerging technology in Africa. This will range from technical to non-technical aspects, including social and ethical as well as public policy considerations. Drawing on examples of trials with micro-grids in Africa and other regions, the AU High Level Panel makes recommendations to accelerate deployment of micro-grids.

- **Massive development of the electricity supply infrastructure beyond current levels is required to meet the demands of Africa's rapidly growing population and universal access targets**
- **Affordable access to energy for productive usage is a prerequisite for the transformation of rural communities and for industrialisation in both urban and rural areas**
- **Grid-expansion is slow and expensive and may not meet universal access targets in the short-term, hence the need for micro-grids as a complementary and parallel approach**

2

Relevance of Problem to Africa's Development

2.1 Development Goals

The case for micro-grids as an essential part of Africa's development can also be justified in the context of the aspirations and goals of the African Union's Agenda 2063, as well as the UN Sustainable Development Goals (SDGs). While linkages can be made indirectly to most of the goals, direct links to Agenda 2063 and the SDGs are depicted in Table 2 below [13].

Table 2: Micro-Grids in relation to AU Agenda 2063 and the SDGs

Agenda 2063 Goal	SDG	Micro-grid relevance
Goal 1 - A high standard of living, quality of life and well-being for all citizens.	Goal 1 - End poverty in all its forms everywhere in the World Goal 8 - Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. Goal 11 - Make cities and human settlements inclusive, safe, resilient and sustainable	Enhance socio-economic well-being through improved quality of life, access to public services, job creation/ entrepreneurship opportunities and industrialization enabled by access to energy.
Goal 7 – Environmentally sustainable and climate resilient economies and Communities.	Goal 7 - Ensure access to affordable, reliable, sustainable and modern energy for all. Goal 13 - Take urgent action to combat climate change and its impacts.	Reduce dependency on fossil fuels.
Goal 10 - World class infrastructure criss-crosses Africa.	Goal 9 - Build resilient infrastructure, promote inclusive and sustainable Industrialization and foster innovation.	Promote access to affordable energy based on emerging technologies which are adapted to Africa's needs.

It is thus evident that the provision of sustainable and resilient energy is an integral part of attaining Africa's development goals as, without energy, the attainment of Agenda 2063 and the SDGs will be compromised. The United Nations General Assembly unanimously declared the decade 2014 – 2024 as the decade of sustainable energy for all, spawning a number of initiatives including the Sustainable Energy for All (SE4All) and the Africa Renewable Energy Initiative. Thus in addition to simply pursuing off-grid generation, Africa must also consider off-grid generation that is clean and green, that is, based mostly on renewable and green energy sources.

2.2 Generation and Access

The installed generation capacity in sub-Saharan Africa's power grid is 90GW (with half of it in South Africa), resulting in about 0.1KW per capita compared to other economies where installed capacity ranges from 1 to 3 KW per capita [7]. Universal access to electricity in Africa is hampered by the cost to expand the national grid. Even where the grid exists, high costs are charged to customers. In 2012, the average cost of generating electricity in sub-Saharan Africa was around US$ 115 per megawatt-hour (MWh), which can increase to more than US$200 per megawatt-hour due to transmission and distribution (T&D) losses, poor maintenance and inefficient system design and operation. This is on the order of 3 to 4 times more than rates in other regions [37] [51].

Agenda 2063 which summarises Africa's development aspirations over a 50-year period aims for an increase by 50% of access to electricity, 50% increase in electricity generation and distribution, 70% of Africans having access to electricity by 2023 and 30% improvements in energy efficiency [13]. To achieve the generation targets, sub-Saharan Africa would have to add about 45GW of generation capacity[2]. PIDA's hydro projects (including the flagship Inga III) have the potential to add 20GW[3] which is just below half of the target. Further generation does not necessarily mean that the electricity will be available to the wider population as this would still require expansion of the grid distribution networks and there would be pressure to balance the energy needs of industrialisation with service delivery needs.

ACHIEVING UNIVERSAL ACCESS

We consider two simple targets - the AU 2063 target of 70% access by 2023 and the SDG target of universal access by 2030.

According to population projections, Africa's population will be 1.45 billion and 1.70 billion in 2023 and 2030, respectively. As of 2014, 645 million Africans had no access to electricity and using that as a baseline, meeting the two targets would require providing access to at least 100 million people per year for the 2023 target and 70 million per year for the 2030 target. According to [8], in 2016 only 9 million people gained access to electricity, clearly signalling that at this rate none of the targets can be met. In fact, predictions are that the 70% target will only be reached in 2040, while universal access would only be attained in 2080.

In terms of generation capacity, universal access and industrialisation would require at least 160GW of new generation capacity of which 60% (96GW) is projected to be off-grid [IRENA]. What is interesting to note from this is that off-grid solutions are seen as being a major contributor to the attainment of universal access.

2 According to [8], 160GW is needed to achieve universal access

3 The Grand Inga Dam would add about 40GW but this is not expected to materialise before 2025

Micro-grids are well-positioned to fast-track the provision of access to energy by-passing the massive investments required to extend existing centralized national grids. It is important to optimize the use of capital since the payback period for micro-grid is of the order of 5-10 years as compared to 20-50 years for investments in centralized grids.

MINI-GRID VERSUS GRID EXPANSION

Africa's low electrification rates can be attributed to the lack of adequate infrastructure and where the infrastructure exists, the high cost of access. Expanding the national grid to reach the unconnected is the most logical option. However, when dealing with rural communities that are far from the grid, sparsely populated and in remote areas, grid expansion becomes uneconomical.

The cost of grid expansion ranges from $19,000 to $22,000 per kilometre for transmission and $9,000 per km for distribution [44][94]. On average, rural populations are not less than 20km away from the nearest substation, making the cost of grid expansion significant. Recovering these costs from rural communities through connection fees is economically feasible where 5 to 10 connections per kilometre of expansion are anticipated. In those countries where the grid has been extended to rural areas, affordability remains an issue, as only 10 to 20% of possible connections are realised [45].

Off-grid micro-grids with utilization of renewable energy resources, allow for flexibility in infrastructural design and scale and are less capital-intensive than grid expansion. Trends in declining costs of energy storage and in renewable energy technologies are helping to make these micro-grids even more cost-effective. According to [51] , grid expansion is a viable option for about 30% of Africa's rural communities while mini-grids are expected to be the route to electrification for 45%.

Another motivation for micro-grids is to reduce the dependence on fossil fuels, thereby reducing carbon emissions and limiting the effects and risks of climate change. Micro-grids can also be seen as an important aspect of climate change adaptation and mitigation. Many households in Africa rely on kerosene for lighting and can spend 20-25% of their income on kerosene. Paradoxically, the cost of using kerosene for lighting, when measured in $/lumen, can be 150 to 600 times higher than using incandescent bulbs or compact fluorescent lights. Not providing access to electricity thus imposes a heavy burden on the poorest of the poor.

2.3 Transforming Communities through Productive Uses of Energy

Micro-grids are well-positioned to fast-track the provision of access to energy, by-passing the massive investments required to extend existing centralized national grids and optimizing use of capital since the payback period for micro-grid is of the order of 5-10 years compared to 20-50 years for investments in centralized grids. The main aim of productive usage is that it enables the communities to derive economic benefit from the use of the energy. In urban settings, such usage may be much easier to define and articulate, whereas for rural communities, there may be a need to "encourage" the development of productive use.

From the perspective of policy makers, productive use would need to be stimulated by enabling rural entrepreneurs to set up or operate businesses that benefit from the energy supplied by the micro-grid. With the right tariff structures, these entrepreneurs would then be able to run profitable businesses while ensuring that the micro-grid is sustainable and, in the case of privately run micro-grids, profitable. Most of the literature on deployment of micro-grids in Africa points to the need to ensure that productive use is built-in so that the grid deployment can be economically viable and sustainable.

Engendering productive use requires a multi-sectoral approach (in the spheres of education, health, agri-business, commerce & trade, and so forth) and enabling conditions for productive use should be initiated prior to the deployment of the micro-grid. This would include an analysis of the community to determine the potential for productive use, stakeholder sensitization on the opportunities, capacity building, training and technical and financial assistance to set up businesses or initiatives. A carefully structured deployment that factors in productive use has the potential to not only improve well-being, but also transform local livelihoods through income generation and job creation [16][94].

- **Under current rates of energy infrastructure investment and deployment, universal access targets will not be met by 2030**
- **In order to reach universal access, investments should increase by about 5 times the current levels**
- **While grid expansion is the best option for providing access, it may be too costly and slow for rural and remote areas in Africa**
- **Off-grid solutions are expected to contribute to more than 50% of generation capacity required for universal access**
- **Deployment of mini-grids in rural communities should be anchored on productive uses to enable sustainability and to have transformative impact**

3

Micro-Grids – Technology Options and Opportunities

The concept of micro-grid is not new. It can indeed be argued that the beginning of the modern micro-grid has its roots in Thomas Edison's first power plant constructed in 1882 – the Manhattan Pearl Street Station [18]. The trend in the past was towards increasing generator sizes justified by economies of scale arguments. The perceived wisdom then was to promote large scale utilities. Times are changing and the era of the traditional utility, as large public or privately owned vertically integrated or even unbundled entities is rapidly passing. The return to micro-grids as a means of solving current challenges regarding the provision of, and access to energy is driven by the need for pragmatic, scalable approaches, especially for rural and remote areas.

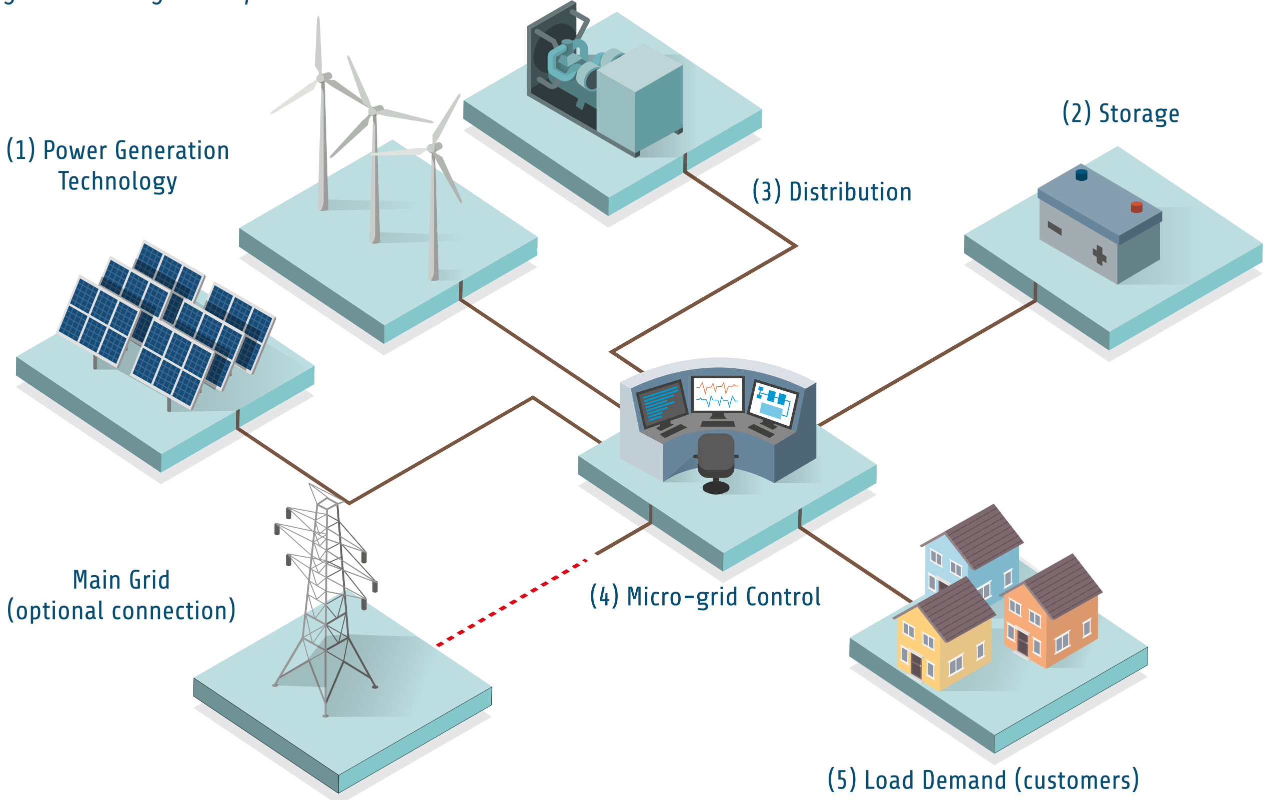
The key technologies underpinning micro-grids in this context relate to the production, distribution and storage of energy especially in the context of renewable energy. Generally, these technologies are mature and can be readily implemented. The key challenge for Africa is adapting the technologies to make them affordable and resilient to the harsh environmental conditions prevailing in rural and remote areas. Of major concern would be the aspect of energy storage to allow for usage of energy at times when micro-grid systems cannot produce energy directly.

In addition to micro-grids being described based on their generation capacity as per the IRENA classification in Section 2, micro-grids can also be described based on their geographical reach, the implementation model and their connection to the national grid [24][40][70][71][72]. Off-grid micro-grids therefore, refer to those that are not connected to the national grid. On-grid micro-grids on the other hand, are those that can be connected to the national grid, either drawing power from or supplying power to the national grid. Off-grid micro-grids may also be referred to as remote or islanded micro-grids. Campus micro-grids are a special instance of micro-grids that may or may not be connected to the main grid and which provide electricity to a closed entity such as a university, a corporate institution or a military base. A community micro-grid is an extension of a campus grid in that it serves multiple customers within a community. A further differentiation can be made based on the fuel source, hence the description of clean energy micro-grids and green micro-grids [9].

3.1 Micro-grid Components

Micro-grid components comprise (1) power generation technology, (2) storage, (3) distribution, (4) micro-grid control and (5) load demand (customers) as shown in Figure 1 below.

Figure 1: Micro-grid Components



The sections that follow examine each of these components in detail, highlighting implementation options as well as opportunities for leap-frogging.

3.2 Fuel Sources and Generation

Generation produces electricity from either fossil fuels (e.g. diesel), the sun (solar or photovoltaic), wind, water (hydro) or biomass. In addition to the specific generator, the generator system may include power conditioners (rectifiers, inverters etc.) and energy management devices.

Power supply can come from a variety of sources, all dependent on the economic and environmental context of the exact siting of the system. Renewable resources have been documented throughout Africa, and in some cases they will be the preferable resource for micro-grids [34]. Use of renewables such as solar photovoltaics, micro-hydro schemes, and to a lesser extent, wind, has been trialled in many countries with varying degrees of success [2][63]. In some cases, generator sets using diesel can also be the basis of micro-grids, either alone (for example in Mali isolated micro-grids have been a relative success) or used in conjunction with a renewable resource [16][87].

In remote areas, diesel generation is common yet it is more expensive. Utility-scale generation based on renewables has put the cost of the order of $0.05 to 0.25 per KWh level, while diesel would come in at more than $0.35 per KWh [55]. Diesel generators have high maintenance costs and energy supply is vulnerable to availability of fuel, which can be further affected by poor transportation systems in remote areas. Hybrid systems, which involve two or more generation sources, are considered when resource availability or fuel supply dictates a need for complementarity of supply or additional reliability [22].

Renewable resources have a notable drawback of an intermittent supply and they cannot be easily 'turned-on' like diesel generators. This creates an obvious problem when users demand power when the resource is not available for example, when there is no sun or wind. During such times, batteries may not recharge sufficiently, leading to power outages. In designing and sizing renewables-based micro-grids, the desired level of reliability should thus be taken into account and adequate measures put in place so that energy is available during times of low availability of renewable resources.

3.2.1 Fuel Sources Research areas and Opportunities to Leapfrog

Africa is on the verge of embarking on its own development trajectory which will inevitably require significant investment in energy sources. Continuous research on these energy sources is pivotal to the sustainability of the micro-grid technology in Africa. Some of the imported energy conversion facilities (e.g. photocells) may need to be adapted to the African environment to enhance performance. Stability challenge is another significant area that calls for continual study. Transient behaviours of these non-conventional energy sources must be studied in relation to the possibility of new dynamic properties cropping up when a number of these energies are combined into various hybrid configurations based on geographical availabilities. This will enable predictive and corrective measures of compensating for probable transient instability to be developed and applied for utility providers to maintain the evolving systems in highly reliable conditions. To achieve this, there must be micro-grid development and demonstration to prove the effectiveness of the technology in integrating multiple renewable energy resources, choice and benefits of energy storage systems. There is a possibility of feeder automation and management of outage systems with advanced controls and communication systems for the overall purpose of improving power supply stability.

3.3 Storage

Micro-grids currently depend on two main options for energy storage: deep cycle batteries and fossil fuel storage (i.e. diesel). Diesel-based storage is usually not preferred as not all countries have a domestic supply and generally this option has high operating costs when compared to renewables. In situations where reliability of supply is not an issue or where the energy demand aligns with the availability of the renewable resource, storage options may be bypassed and energy consumed as it is produced. For micro-grids deployed in remote areas which depend on solar, wind or biomass and where the generation cycles may not always align with demand, storage of excess energy is essential to regulate the availability of power. Typical storage mechanisms involve battery banks which are charged as excess energy is produced [4][35][57][58][68].

The two main types of batteries available are lead acid [with sub-types Absorbed Glass Mat (AGM), NiCD, Flooded, gel] and Lithium-ion batteries. Lead-acid batteries are a mature technology but have the drawbacks of being physically heavy, have a long recharging cycle (~8 hours), fewer lifetime recharges, and have periodic maintenance requirements. Lithium ion (Li-ion) batteries which have a higher energy density, are more resilient and have a longer life cycle, and are emerging as a preferred alternative to the more common lead acid batteries [60][62].

Considering that storage can contribute up to 40% of micro-grid project costs, battery technology focuses on achieving higher energy density (more power) for longer durations while decreasing costs. A target currently being pursued is to bring costs from current average levels of $350 per KWh to below $100 per KWh [25][31]. (In a typical micro-grid rated at 100KWh, the cost of batteries alone would be of the order of $35,000). Battery storage is expected to be the game-changer for the energy sector in much the same way that cell phones changed the telecommunications sector [69]. A different type of battery technology are Redox flow batteries which store their energy in the electrolyte (fluid) and enable energy and power capabilities that can be scaled independently. It is to be expected that hybrid solutions which combine lithium-ion and flow technology will provide an optimal solution, balancing power with longer duration storage requirements [28].

Lastly, new lithium-air battery technology can in theory achieve the highest energy density among current battery systems, and these are expected to become commercially available in a few decades. Investing in research into these and other battery technologies should be considered as an option for Africa. In South Africa, Eskom has recently established a research facility for energy storage [29].

3.3.1 Storage Research Areas and Opportunities to Leapfrog

While most lithium-based batteries have unstable chemistries and raise safety concerns since they are susceptible to combustion, lithium-ion phosphate batteries have a reduced risk for fire. This, coupled with a much better life cycle, makes them a better emerging option for micro-grid applications. There is room for further research in their application for micro-grids as well as the emergent lithium-air technology, which is still in early stages of development. Micro-grid deployment should also be accompanied by research in repurposing and recycling of batteries. Africa can leapfrog through investment in large-scale recycling, learning from the US where 97% of lead-acid batteries are recycled.

Another emerging option for research is the use of flywheels which store rotational energy and can therefore replace or help to prolong the life of batteries in micro-grids. Using flywheels with batteries can lower the total cost of ownership by up to 30%, compared to a battery-only system [6]. It should be noted, however, that a single flywheel could weigh as much as 2 tons, having serious implications for transportation to rural and remote areas.

3.4 Distribution

Distribution transfers energy from the point of production to the point of use or consumption. In designing a distribution network or system, the type of system (AC, DC, single phase, three-phase) will be impacted by the geographical span of the area to be serviced and has implications for the cost of the network, as well as the type of end-user load the network can supply. The distribution network also has implications for how usage can be recorded and metered to enable billing of consumers.

Micro-grids can operate with alternating current (AC) or direct current (DC) or a combination of both, which can be referred to as a hybrid AC/DC system. Most applications of DC micro-grids are limited to efficient LED lighting, mobile phone charging and other appliances with lower power draws. Generally, larger micro-grids supplying higher energy requirements have more developed distribution systems and tend to be AC based. The benefits of an AC system are widespread availability of appliances and power components. Converters (inverters or rectifiers) are used in order to change the voltage from DC to AC and vice versa, depending on the end-user appliances.

3.4.1 Distribution Research Areas and Opportunities to Leapfrog

Advancing DC micro-grid technology (example solar panels, LED lights, DC appliances) is of particular interest for Africa since for most rural and remote areas, off-grid implementation will hinge on DC technology. Block-chain micro-grids are another emerging area which focuses on enabling consumers to buy and sell electricity using cyber-currency [71]. For emergency and disaster applications, the ability to rapidly configure and deploy micro-grids through autonomous driverless electric vehicles (EVs) is being proposed [71]. This could prove to be a solution for remote areas where, instead of setting up dedicated infrastructure in areas that are not commercially viable, energy could be transported by these EVs from community micro-grids to the point of need or usage.

3.5 Grid Connection & Micro-Grid Control

Micro-grids can either be connected to the main grid or stand-alone (fully autonomous) with varying implications. Where the main power grid is nearby, a switchable connection can be incorporated to manage the power flows between micro- and main-grids. Isolated micro-grids operate fully autonomously from the main grid. In this arrangement, there is no option to receive or provide power to the main grid in the event of a shortage or oversupply. As a result, the availability or reliability of the system will be dependent entirely on the capabilities of the micro-grid. In some cases, even without 100% reliability, an acceptable basic electricity service can be provided economically.

Where possible, coupling a micro-grid with a larger centralized grid through a grid-tie inverter can provide high levels of reliability as the central grid can be used when supply from the micro-grid is inadequate. In most African countries the national grids do not extend to rural areas. In the absence of regulations for feed-in tariffs or net-metering which is also the case in most African countries currently, fully-autonomous micro-grids are easier to implement and most common. Micro-grid controllers are used in both off-grid and on-grid installations. The controllers are used to ensure that generating equipment functions at predefined operating points and within set limits. Such connection and disconnection of components is seamless and that the micro-grid can recover from failure [5]. With on-grid systems, the controller also facilitates switching to or from the grid based on consumption and energy storage levels.

3.6 Load Management Subsystem

Equipment at the end-user or consumer side includes all the appliances and electrical loads, metres, wiring and other associated equipment. Smart metres which rely on Information and Communication Technologies (ICTs) enable micro-grids to operate more efficiently through optimization of design, automated tariff collection (payment through mobile phones and other electronic means) and demand side management and control [86].

3.6.1 Load Management Research Areas and Opportunities to Leapfrog

Research into integration of ICTs and mobile telephone into micro-grid deployment is a fertile area for further research, including how to transfer lessons learned from the mobile industry to micro-grids [32][49][63].

3.7 Deploying Micro-Grids

As seen from the preceding sections, the spectrum of technological options for micro-grids is relatively wide as the scale of a micro-grid can range from a collection of a few connected households completely isolated from the centralised grid, to a medium-scale scheme micro-grid that connects thousands of customers and is capable of interconnecting with the main grid.

3.7.1 Use – Cases and the Choice of Grid Deployment

The Multi-Tier Framework for energy access, captures the spectrum of energy for productive usage along several parameters, including the quantity of energy available over the course of a day [23]. The energy available can also be mapped to typical applications. Figure 2 below is an adaptation of the Framework showing the tiers and indicative applications as suggested by the SE4All Global Tracking Framework4 [20].

Figure 2: Mapping of household electricity needs, indicative uses and grid deployment

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Minimum Supply	0	3W	50W	200W	800W	2KW
Availability (hours/day)	0	4	4	8	16	24
Indicative Use	N/A	LED light, phone charging	Multiple lights, air circulation (fan), television, Phone charging	Tier 2 + small appliances	Tier 3 + medium appliances, water pumping	Tier 4 + large appliances
Indicative Grid Type	N/A	Stand alone	Stand alone	Pico, Nano (Micro)	Nano, Micro	Mini, National

While it may not bring out all the nuances, the diagram is a useful reference in determining what kind of energy supply would work best for a particular category of users. Indicative grid types are suggested using the IRENA classification. From the diagram, it is seen that for low energy uses, stand-alone systems on a per-household basis may make economic sense and that as the intensity of usage increases, interconnection through nano, micro or mini-grids may be justified. It should be noted that Tier 5 represents

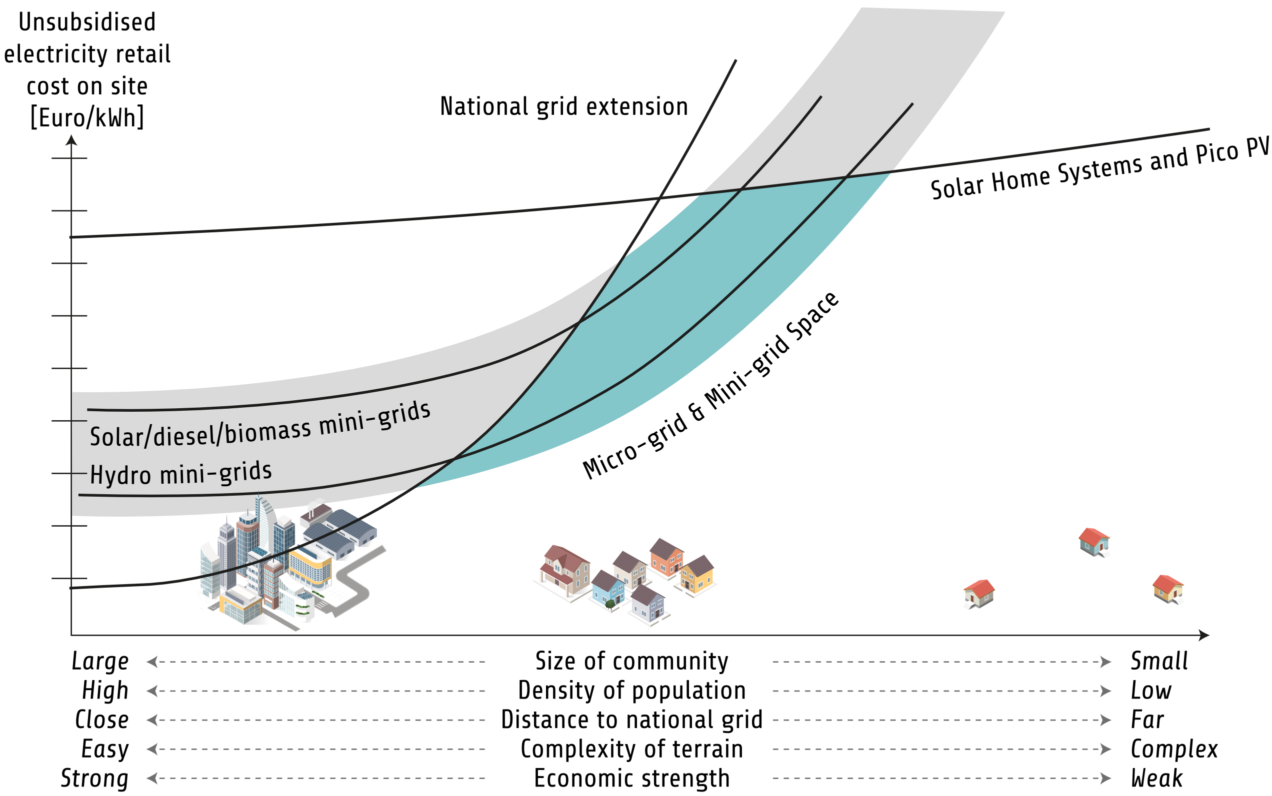
4 The SE4All Global tracking Framework is the pre-cursor to the Multi-Tier Framework which was developed in conjunction with SE4All partners by the World Bank through its Energy Sector Management Assistance Programme (ESMAP)

the ideal situation and the goal of any electrification strategy should be to not only provide basic Tier 1 access but also to move users gradually across the continuum until they attain Tier 5 access. As such, planners must consider how micro-grids are scaled up over time as demand for more electricity grows along with the need for more reliable power.

3.7.2 The Space for Micro-Grids

The preceding sub-section showed micro-grids as a potential solution when user requirements started to increase from Tier 3 onwards. Figure 3 illustrates how parameters related to the geography, density and size of communities also influence the choice of energy access solutions [40].

Figure 3: Micro-/Mini-grids Space Compared to Alternatives



Specifically, the diagram illustrates how the cost of access for stand-alone (Solar Home systems and Pico PV), mini-grid and national grid extension varies with these parameters. The cost of stand-alone systems increases only moderately and is, for all intents and purposes, in variant to the parameters. National grid extension is justified for communities that are large, dense and close to the grid. The cost of grid extension increases exponentially. As communities become smaller, less dense and more dispersed or displaced from the grid and the cost of grid extension becomes significantly higher than either stand-alone or mini-grids. In large, dense communities that are close to the national grid, mini-grids may be more expensive than grid-extension but are more economical than stand-alone systems. As communities decrease in size and become less dense, micro-grids start to make economic sense relative to grid extension. As communities become smaller and more dispersed, stand-alone systems are a better option. As such, micro-grids find their space when grid extension is not economically viable, where the population density and community size leverages economies of scale over stand-alone approaches. This is illustrated by the area that is shaded red in Figure 3. Grid Deployment Research areas provide opportunities to leapfrog.

Africa is a vast continent and any attempt to build super grids to serve all communities, as currently exist in developed countries, will in most cases be economically unfeasible and politically challenging. Moreover, the trend in developed countries is towards development of smart grids and micro-grids based increasingly on development of distributed renewable energy resources because of the advantages of such systems. These advantages include resilience, flexibility, as well as less vulnerability to widespread failure especially in a world of uncertainty where large centrally controlled power systems are vulnerable to cyber-attack. This poses a major risk not only to national economies but also political stability. Research targeting aspects such as sustainable energy mixes, centralised versus distributed approaches and the integration of ICTs for smart grids are opportunities for Africa to lead by example in micro-grid deployment [19][30].

- **African countries should establish centres for micro-grid development and demonstration to prove the effectiveness of the technology in aspects such as integrating multiple renewable energy resources, choice and benefits of energy storage systems**
- **Storage is a significant cost of micro-grid deployment thus Africa should invest in battery technology research focusing on achieving higher energy density (more power) for longer durations while decreasing costs**
- **Leverage ICT and mobile boom by Investing in research on integration of ICTs and mobile telephony in micro-grid deployment**
- **Currently fully-autonomous micro-grids are easier to implement and most common in Africa however efforts should be made to couple these micro-grids with larger centralized grids so as to provide high levels of reliability**
- **Even where micro-grids may not make economic sense, rural electrification strategies may opt to implement micro-grids on the basis of providing energy access to stimulate productive usage and rural industrialisation.**

4

Micro-Grid Implementation in Africa

Over the last 5 years there have been concerted efforts to promote micro-grids in Africa, driven partly by political imperatives as well as development objectives [98]. The penetration of micro-grids is affected by the strategy adopted for rural electrification. Some countries elect to maintain a centralized grid which is then extended to service new customers; other countries incorporate mini-grids as part of the strategy of increasing coverage while others favour a totally decentralized approach to rural electrification.

4.1 Implementation at National Level

There are several countries that are emerging as front-runners in the deployment of micro-grids and in the enactment of policy and institutional reforms to support micro-grids.

From the various initiatives and implementations key findings emerged in relation to regional participation, partners and stakeholders involved, type of assistance, operational models for micro-grids and the sector or sub-sector focus as follows:

Regional participation – There is a noticeable lack of implementation in Central Africa both among the individual countries and at the level of the regional economic community, for example ECCAS.

Operational models and productive use – Choices have to be made as to whether micro-grids will be wholly funded by government, by the private sector, by utilities, by communities themselves or through different kinds of partnerships. For rural areas, community ownership is an option if the community is empowered to manage the micro-grid sustainably. Some projects succeeded in mobilising funding either from the community or through crowd-funding.

Stakeholders and Partners – Most initiatives are started by development partners and have the support of government with funding from Overseas Development Assistance (ODA), public resources and private investment. The level of engagement with civil society organisations is lower, even in those cases where micro-grids are implemented as community-driven projects.

Sector focus and productive use – Micro-grid programmes also address productive uses of technology in sectors such as telecommunications, agriculture, water, tourism, education and health. Giving communities options for productive use of the energy helps so that they can afford to pay while at the same time having surplus for their socio-economic well-being.

Type of Assistance – Most programmes focus on technical assistance for feasibility studies, business plan development as well as technical, social and environmental assessments. In a few cases, support is provided for financial modelling, market and risk assessment and capacity development. Technical and financial support is complemented by policy advisory services, consumer education and awareness and stakeholder dialogues.

4.2 Implementation at Regional Level

The regional integration dimension of mini-grid implementation would consider areas for harmonisation (policy, regulatory, technical), as well as inter-connection of mini-grids across boundaries. In the current AU framework, this would entail working with, and through Regional Economic Communities. It should be noted that some of the RECs – EAC, ECOWAS, SADC – already have initiatives that are geared towards renewable energy implementation, as well as the harmonisation of legal and regulatory environments across member states. All the regions also have power pools based on the existing national grids, and it is conceivable that similar approaches to pooling power could be envisaged for micro and mini-grids. The linking of micro-grids is especially important for border towns where the current trend is towards One-Stop Border Posts. Such linkages would also make self-sustaining micro-grids possible with demand anchored in the border towns and their need for energy which would then accrue to outlying areas. The interconnection of micro-grids would enhance the security of energy supply and also help to lower the cost of access to energy.

The Africa-EU Energy partnership works to increase investment in energy infrastructure and has done considerable work to facilitate micro-grid deployment. This includes the mapping of energy projects, in Africa, the development of best practice guidelines and a micro-grid policy toolkit. The Africa-EU Renewable Energy Cooperation Programme (RECP) supports the development of markets for renewable energy in Africa through four areas that focus on enabling and triggering investments in renewable energy projects [98]. The four areas are policy advisory, private sector cooperation, access to finance and innovation and skills development. The Africa Renewable Energy Initiative (AREI) was launched in 2015 with the goal of providing universal access to energy based on renewable sources by 2030.

The Africa Renewable Energy Access programme (AFREA) is supported by the World Bank through its Energy Sector Management Assistance Programme (ESMAP). Through its Lighting Africa initiative, AFREA aims to provide 250 million people with access to off-grid energy by 2030. AFREA has also established the Africa Electrification Initiative, a platform that connects policy makers, regulators, researchers and NGOs for information-sharing on implementation of electrification initiatives. The EletriFi programme, funded by the European Commission and USAID's Power Africa, supports renewable energy projects, especially those working on decentralised (off-grid) solutions, by bridging the gaps in structuring and financing, stimulating private sector participation and mobilising financiers. In its last round of application for financing, out of about 280 applications, almost 70% were from 10 countries: Nigeria, Tanzania, Zambia, Kenya, South Africa, Madagascar, Rwanda, Uganda, Senegal and Ghana, and more than 30% were for mini-grid or stand-alone electrification projects [39].

The African Development Bank (AfDB), through its New Deal on Energy for Africa, is working with partners to achieve universal access to energy in Africa by 2025 through a Transformative Partnership on Energy for Africa which focuses on innovative financing through public-private partnerships [8]. The New Deal focuses on four targets: increasing on-grid generation by 160GW, increasing on-grid distribution and grid connections to create 130 million new connections, increasing off-grid generation to add 75million connections, and increasing access to clean cooking energy for 130 million households.

The SE4All is a global initiative which focuses on three objectives: ensuring universal access to energy, doubling the rate of improvement in energy efficiency, and doubling the share of renewable energy sources in the energy mix. In March 2017, the Africa Union Commission's Specialized Technical Committee (STC) on Transport, Transcontinental and Interregional Infrastructures, Energy and Tourism Africa endorsed the Green Mini-Grids (GMG) Strategy for Africa developed by SE4All. The strategy aims to create an enabling environment for development, finance and sustainable implementation of GMGs [9].

In sub-Saharan Africa, ECOWAS has served as a model for other RECs to emulate in the support of renewable energy initiatives and programmes. The ECOWAS Centre for Renewable Energy Efficiency (ECREEE) was endorsed by member states in 2008, and a formal secretariat established in 2010. In 2013, ECOWAS adopted its Renewable Energy Policy with targets to implement 60,000 mini-grids providing 3.6GW of energy to 71 million people by 2020. The policy also focuses on harmonisation of policies, laws and regulations across its member states. With support from the EU, ECOWAS has in 2017 developed a toolkit to support ministries, regulators and utilities in the design of RE tariffs. ECREEE is currently working on a project to develop a regional energy market investment strategy that will focus on promoting business opportunities for women in the energy sector. ECREEE established and manages the ECOWAS Observatory Renewable Energy and Energy Efficiency - an online platform that provides project and country specific information on renewable energy projects in the region [92].

Ministers responsible for Energy in EAC took a decision to establish a Centre for Renewable Energy and Energy Efficiency in 2012 and the EACREEE was officially inaugurated in 2016. The Centre has since published its first report on the status of RE in East Africa and will work towards a harmonised RE policy framework for the region. The EAC Regional Strategy on Scaling-Up Access to Modern Energy Services aims to increase access to energy services through high impact, low cost scalable approaches in its member states. The EAC is also working on technical capacity building for small hydropower projects.

SADC member states adopted the SADC Protocol on Energy in 1996 to promote harmonised approached to the development of national energy policies and resources. As part of its Regional Infrastructure Development Masterplan, which was developed in 2012, SADC has an Energy Sector Plan focusing on both the hard and soft aspects of energy infrastructure development. The plan aims for an energy mix having 33% renewable energy by 2020 with only 5% of this being off-grid (targets for 2030 are 39% and 7%, respectively). In 2015 ministers responsible for energy endorsed the establishment of the SADC CREEEE, pledging to add 17GW of energy from renewable sources to SADC's energy mix by 2019. Going by the energy sector plan, the expectation is that less than 1GW of this would come from off-grid generation. The SACREEE secretariat was formally opened in Namibia in 2016.

The COMESA-EAC-SADC Tripartite brings together nearly 600 million people and close to half of Africa's countries with the objective of strengthening and deepening their economic integration. The Tripartite strategy rests on 3 pillars: market integration, infrastructure development and industrial development and activities focus on the harmonisation of policies and programmes across the three Regional Economic Communities (RECs).

Each of the 8 RECs in Africa is associated with a regional power pool - there is a power pool for each of the 5 geographic regions of the African Union. SADC was the first region to establish a power pool in 1995 with the objective of facilitating cross-border trade in electricity and ensuring reliable and affordable electricity supply across the region. The East African Power Pool (EAPP) was established in 2005 and subsequently became a specialised institution of COMESA. Each REC also has an associated regional umbrella body for energy regulators which interfaces with and supports the work of the RECs.

- **Regions that are lagging behind should learn and benefit from the experience of those that are leading in micro-grid implementation.**
- **Strategic choices should be made on the operational models of micro-grids, taking into account the need to transform rural communities.**
- **Productive use should be structured on a multi-sectorial approach.**
- **Programmes to stimulate micro-grid deployment should provide a range of policy, technical and financial services, notably technical assistance for feasibility studies, business plan development and technical, social and environmental assessments, policy advisory, consumer awareness.**

5

Socio-cultural and Ethical issues

Social and ethical considerations deserve serious attention at the conception of electrification projects, especially for green field projects where there has previously been no electricity. This is because electricity can profoundly change the social, economic and cultural context of a community. Relationships within the community, including roles of men, women and children, can be fundamentally affected by the introduction of electricity. Deliberate well-structured community engagement at an early stage is critical to ensure clear understanding of how to undertake the project, which can vary from place to place. Some of the aspects that need to be investigated and handled appropriately are elaborated in the sub-sections that follow.

5.1 Social considerations

- Community leadership and protocols -- Understanding and respecting social norms is important for any enterprise that seeks to bring change to a community. A clear community engagement strategy, through which communities and their leaders are included in key decision-making, is thus critical for micro-grid deployment.
- Impact on employment -- The expected impact of introducing electricity to a community is increased opportunities for employment. Yet, there are sometimes some unintended outcomes of electrification which have the reverse effect. For example, fuel wood use generates at least 20 times more local employment in South Asia than energy from oil products (per unit of energy). This unintended impact must be considered during project conceptualization

5.2 Ethical considerations

- Community participation in project delivery is essential. Major decisions should be taken in consultation with local community leaders. Consider models that involve part ownership of the facilities by the local community.
- Providing sustainable solutions for communities – avoid undue external dependence and deployment of inappropriate models that cannot be supported over the long term.
- Land use for energy production – consider local land use and avoid conflict with local community.
- Health & safety – ensure appropriate health and safety is considered in design and operation of the micro-grid.
- Standards for micro-grid components – ensure appropriate standards are adopted and used to screen components used in the micro-grid.
- Safe end of life disposal – micro-grid components, especially batteries that contain lead, which is harmful if it leaks into the water system, must be managed responsibly.

- Community education and capacity building – ensure the local community is educated on use of the system, as well as its operation and maintenance.
- Equality of access – micro-grids could be the basis of local economic development for rural poor communities which are not always a high priority for public or private investment.

5.3 Gender Impact and Considerations

Gender inequalities in the energy sector manifest in several ways: gender gaps in energy access, gender gaps in the energy labour market, gender gaps in energy-related education and gender gaps in decision-making. Due to the lack of access to education, women are often employed in low-qualified and non-technical jobs in the energy sector. This may be related to the fact that fewer women than men undertake studies in science, technology, engineering and mathematics (STEM). Moreover, the average digital literacy of women is lower than that of men. Women's participation in the energy labour market is also discouraged by gender stereotypes, which portray the energy sector as a technical working environment that is unsuitable for women [1][17].

With regard to access, electrification impacts men and women differently as a transition from traditional energy sources (wood, charcoal) to electricity changes the household dynamics. Given the heavy burden women are typically tasked with in managing household energy supply, transition to more efficient, cleaner and more affordable energy is usually a boom for women. Long-term benefits include better access to education for women and girls [82]. In the labour market, women have the potential for creating and benefiting from green employment. Examples of entrepreneurial and productive use of sustainable energy include water pumping for potable water and drip irrigation systems, labour saving technologies for agricultural production, agro-processing and reduction of post-harvest losses.

- **Social and ethical considerations should be incorporated during the conceptualization of electrification projects, especially for green field projects where there has previously been no electricity**
- **Community engagement and participation, taking into account social and cultural norms, is essential to success of mini-grid implementation**
- **Public and private investment in micro-grids should focus on poverty reduction and wealth creation to transform rural communities**
- **Micro-grid deployment should mainstream gender requirements and ensure that women are empowered not only with affordable access to energy but also opportunities to benefit from entrepreneurship and productive use**

6

Risk Analysis for Micro-Grid Implementation

The risks associated with adoption of micro-grid technology are discussed using a PESTLE (Political, Economic, Social, Technology, Legal and Regulatory and Environment) approach under the headings of [38]:

6.1 Political

In addition to political will expressed through government leadership, micro-grid projects as with other development projects, will be impacted by the political stability of a country and the stability of its region and neighbours. Lack of stability will make it difficult to attract investment for micro-grid projects, especially in remote areas where the time to get significant returns may be longer than in urban settings. Trade restrictions and reforms also pose a risk to micro-grid projects since most countries in Africa have to import the equipment and also outsource the technical skills for implementation. Restrictive labour laws also affect the success of micro-grid projects.

6.2 Economic

Inflation and cost of living are economic factors that will have an impact on the ability of consumers to pay for electricity. It is well-established that in most African countries the tariffs for electricity are not cost-reflective and there is a lot of subsidization by governments. Implementing micro-grids which would either require private investment or community ownership poses a risk whereby for profitability and sustainability, cost-reflective tariffs would render access to electricity out of reach for most people [33]. Countries such as Mali, Namibia and Senegal that have implemented micro-grids with cost-reflective tarrifs provide valuable lessons for the rest of the continent. Limited access to finance and credit is an impediment to leveraging private sector participation in micro-grid projects, especially for local actors. This is further exacerbated by import taxes and duties and unstable currencies which raise the cost of implementation and hence increase the cost to the consumer.

Key to micro-grid development are business models that are holistic, adaptive and robust. Apart from adequate demand modelling and feasibility studies, micro-grid business models should be based on the promotion of productive uses of energy to sustain demand. This becomes particularly important for sites which do not have an anchor business customer to take up the generated electricity. Revenue collection methods (prepaid, pay-as-you-go) are an integral part of the sustainability of micro-grids which goes hand-in-hand with cost reflective tariffs that ensure adequate returns for investors [16][21].

THE BUSINESS CASE FOR MINI-GRIDS

With expectations that the energy demand of 45% of Africa's rural population will need to be met by mini-grids, establishing the business case for mini-grid deployment is essential. Mini-grids will need to be developed through a variety of models, including PPPs and community-owned and operated mini-grids. Whatever model is chosen, sustainability will require that deployment and operational costs are recovered in the case of community ownership and that mini-grids are profitable where private capital is invested. Current experience shows that returns on investment for mini-grid projects range from 10 to 15% compared to 20% for on-grid projects. Private mini-grid operators in Africa expect a project Internal Rate of Return (IRR) of at least 12% and an equity IRR above 16%. These IRRs are considered to be adequate by social entrepreneurs but not for commercial investors.

Mini-grid deployments usually work with a pay-back period of between 5 to 7 years compared to the 20 to 30 years that is typical of grid expansion investments. Mini-grid developers are faced with the choice of deploying smaller mini-grids that require moderate investment and are less profitable versus larger grids which are more profitable over a longer period of time. Deploying larger mini-grids thus makes sense when anchored in productive use and the sale of generated capacity is assured.

6.3 Social

The demographics of a country, as well as education and literacy levels, will impact the success of micro-grid projects. Currently, Africa faces a situation where close to 70% of the population lives in rural areas and more than 60% of the population consist of youth. While the high rural population makes the case for micro-grid deployment, it also presents risks with respect to expectations, attitudes and beliefs. For instance, consumers in rural areas might have the perception that electricity, like other services such as education and health, should be provided by the government at no cost to them. Low levels of education and literacy levels would add to this problem. On the other hand, the large youth population is associated with increasing rural to urban migration which if unchecked, would limit the use-case for micro-grid deployment in rural areas and might in some cases cause projects to fail due to insufficient demand. Implementation of micro-grids should thus take into account stakeholder integration and the creation of local business activities and opportunities to stimulate and sustain demand for electricity.

6.4 Technology

Micro-grid implementation requires that there is a skilled and technologically capable workforce to install, operate and maintain the micro-grids. There is thus an opportunity for Africa to develop a critical mass of scientists, engineers and technicians around micro-grid technology. The downside to this is the risk of failure of projects due to an inability to maintain installed infrastructure. The deployment of micro-grids is dependent in part on the availability of other infrastructure such as transport and telecommunication networks. Where this complementary infrastructure is lacking, there is a risk that micro-grid projects will not provide maximal benefit, and in some cases, may even affect the viability of the project.

The lack of ownership of intellectual property in micro-grids means that Africa would have to pay to license or commercialise micro-grid technology and components. The inability to pay for technology licensing might pose a risk in that once a micro-grid solution is deployed, there is little room to adapt or change technologies, especially where proprietary solutions and technologies are used.

From a programme development perspective, innovation and IP development could be encouraged through competitions and grand challenges on topical issues on micro-grid deployment for rural and remote communities.

6.5 Legal and Regulatory

Micro-grid deployment faces risks not only from technology and operational considerations but also from perceived and actual risks that affect private sector investment. The major concern for private sector investors is the predictability of the regulatory environment and the ability to generate profitable returns on investment. It is thus important to streamline procedures and establish independent regulatory authorities with defined licensing and registration regimes for independent power producers.

Limited consumer awareness can impact the success of micro-grid projects, particularly where the cost of micro-grid access might be higher than that of access to the national grid. Given Africa's socio-cultural dynamics, there is usually cross-subsidization of access to services in rural areas by family members in the urban areas. The willingness-to-pay may be a risk if the urban consumers are not made aware of the differences in cost of access between rural and urban areas. The legal and regulatory environment should therefore, take into account consumer needs and interface with the relevant consumer advocacy groups. This will ensure that any issues related to micro-grid implementation which are likely to affect consumers should be discussed and negotiated prior to deployment. Where consumer advocacy groups do not exist, government should take steps to encourage and support their establishment.

6.6 Environmental

Implementation of micro-grids that are based purely on renewables face the risk of unstable power supply due to climate and weather patterns. As such, detailed analysis of prospective sites should be undertaken and measures put in place to back up the electricity supply with other means when renewable sources are limited or unavailable. The use of diesel as the primary or back-up source of energy introduces issues of ecological contamination due to spills as well as contribution to carbon emissions. On the other hand, the use of batteries for storage also poses risks of contamination and pollution from the unsafe disposal of batteries. Overall, micro-grids and their components will increase the generation of e-waste and the mitigation of environmental degradation should form part of the overall assessment prior to deployment. Recycling schemes should be put in place and opportunities exploited to develop recycling technologies.

Thus micro-grid programmes should include development of tools and instruments to assess micro-grid risks which should be discussed transparently with financiers, developers and stakeholders alike. This would enable risk mitigation to be mainstreamed into project development and allow micro-grid projects to identify options for dealing with risk. Ultimately, national strategies would aim to develop standardised risk management procedures.

- **Business models that are holistic, adaptive and robust are key to micro-grid development.**
- **Implementation of micro-grids should take into account stakeholder integration and the creation of local business activities and opportunities to stimulate and sustain demand for electricity.**
- **Micro-grid implementation is an opportunity for Africa to develop a critical mass of scientists, engineers and technicians around micro-grid technologies.**
- **Procedures for mini-grid deployment should be streamlined, and independent regulatory authorities established with defined licensing and registration regimes for independent power producers.**
- **Micro-grid deployment can contribute to e-waste therefore, recycling schemes should be put in place and opportunities exploited to develop recycling technologies.**

7

Policy and Regulation

An enabling public policy environment is critical to the success of electrification based on micro-grids, in particular for rural application. The lack of clear policy, standards and regulatory oversight has been identified by many players in the market, including trade and standards associations, as a source of increasing concern. It is therefore important to promulgate appropriate rules, regulations and procedures to guide deployment and operation. In the sub-sections that follow, some critical public actions for the success of micro-grids are presented [4][16][36][50][65][90][93].

7.1 Rural electrification strategy and implementation

Some of the political decisions that have to be taken are whether or not mini-grids should form part of the rural electrification strategy since most national grids are either wholly or partially owned by governments and the introduction of mini-grids can be seen as detrimental to the expansion of the national grid. Countries need to have integrated electrification plans which indicate the roll out of electrification. This should identify which areas are due to get grid electricity by when, and with clearly spelt-out roles for the development of on-grid and off-grid energy supply.

Further decisions have to be made about off-grid versus on-grid micro-grids, that is, whether mini-grids generate and distribute their energy independently or energy generated should be fed into the national grid. This has an impact on tariff setting as well since off-grid solutions will mandate cost-reflective tariffs whereas on-grid solutions might benefit from cross-subsidised tariffs. Lastly, decisions have to be made about how mini-grids will be financed – whether by government, private sector or through PPPs. These decisions are foundational to the policy and regulatory frameworks and also determine the type of operator models to employ.

7.2 Establishment of Regulatory Authorities

The regulatory authority has the primary role of protecting the consumers and safeguarding the investment. Some primary actions that the regulatory authority must take include the following:

- Determine who will develop, own and operate micro-grids;
- Develop, measure and quantify the environmental benefits of micro-grids; and
- Provide licence and regulatory oversight

A key function of regulation must be to protect the public from exploitation by what will effectively be private monopolies within the licence area. Countries that have developed regulatory frameworks have exhibited better performance in attracting necessary investment, for example South Africa, Rwanda [10].

7.3 Development of commercial framework for pricing

7.3.1 Adoption of technical standards

To safeguard customers against substandard products which can undermine confidence in renewable energy such as solar, it is essential to adopt and enforce standards for critical components such as solar panels, inverters, charge controllers and batteries. Currently, most countries do not have mandatory standards for renewable energy products.

Enforcement of standards should include mechanisms for dealing with unscrupulous players in order to avoid negative consequences arising from the following:

- Loss of public confidence in new technologies, especially if substandard products are allowed to proliferate without adequate performance guarantees;
- Health and safety concerns – lack of standards and regulation can lead to unsafe systems being installed leading to accidents. This could include unsafe end-of-life disposal of components such as batteries; and
- Unscrupulous service providers – some unscrupulous developers or service providers could install poor systems and not be accountable for negative outcomes.

7.4 Operational Models

The models used to deploy micro-grids range from private to community initiatives. Distinctions can be made between utility-run mini-grids, privately run min-grids, community or cooperative schemes, or a combination, leading to these classifications: utility, private, community and hybrid operator models. Regulatory and policy considerations have to factor in the operational models allowed, as well the generation or distribution model, and whether the mini-grids are being implemented purely for a localised area or with intent to distribute energy generated to outlying areas.

7.5 Tariff Structure

A clear pricing basis must be developed that takes due account of the impact of micro-grids on the whole energy system. Pricing must be both logical and fair when compared to the main-grid tariff structure. It might be worth, for example, extending the concept of renewable energy feed- in tariffs to micro-grids.

There are three basic types of tariffs:

- Energy-based tariffs depend on the actual electricity consumed and are thus based on measured kWh.
- Power-based tariffs are based on the expected power consumption, which in turn determines the maximum power available for the consumers. These tariffs are calculated on a Watt basis.
- Fee-for service tariffs charge for services provided and not per unit of energy. The tariff is based on kg, hour, litres or other units of service.

Another way of classifying tariffs is to consider whether they are break-even tariffs, profitable tariffs or free-of-charge. Break-even tariffs are typically used in community mini-grids to ensure cost-recovery of capital and operational expenditure while profitable tariffs would be higher to enable sufficient returns on investment for private sector operators. The problem with profitable or cost-recovery tariffs is that they are usually higher than the tariffs on the national grid. Free-of-charge (pro-poor) tariffs aim to ensure that a minimum level of service is made available to those that cannot afford to pay. Poorer customers receive subsidised service either directly through government subsidies or indirectly through higher tariffs for high-consumption customers.

The emerging model among privately-owned mini-grids is to offer a pre-payment or pay-as-you-go service similar to how mobile services are provided. While prepayment enables more predictable revenue collection for the mini-grid operator, it does not address the issue of capacity to pay among the poorest. As such, there is need for safeguards that ensure that the poor will get a minimum level of service and an agreement would need to be reached between government and the regulator on how this minimum level of service would be financed.

- **A regulatory environment is essential to ensure a level playing field and to ensure adherence to agreed service levels and operational safety concerns.**
- **African countries should adopt and enforce standards for the most critical components such as solar panels, inverters, charge controllers and batteries**
- **A clear pricing basis must be developed that takes due account of the impact of micro-grids on the whole energy system**
- **Tariffs will need to ensure an adequate return on investment for viable and sustainable mini-grid deployments**
- **Pro-poor tariffs and built-in subsidies should be developed to ensure that a minimum level of service is made available to those that cannot afford to pay**

8

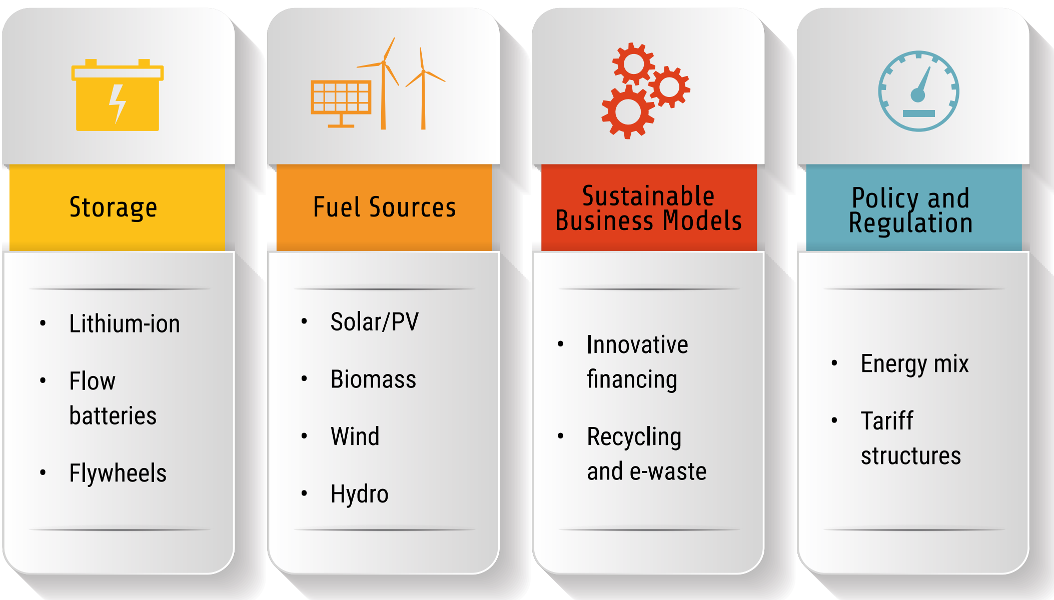
Research, Development and Demonstration

8.1 Research and Development Focus and Infrastructure

As discussed under the various subsections in Section 4, mini-grid deployment offers opportunities for research in a number of areas: battery storage, fuel sources (PV, biomass, wind, hydro), sustainable business models, policy and regulation. These are summarised in Figure 4. The Research and development infrastructure required would depend on specific areas that projects or countries would focus on. A pragmatic approach might be for projects, countries or regions to take up research areas based on their comparative advantage.

For research focusing on battery storage and fuel sources, the infrastructure would include physical laboratories with simulation, prototyping or testing capabilities. Additionally the concept of "living laboratories" could be adopted, using onsite implementations for research activities. Implementation of micro-grid research should align with, and be informed by the African Union Science Technology and Innovation Strategy for Africa (STISA 2024) [12].

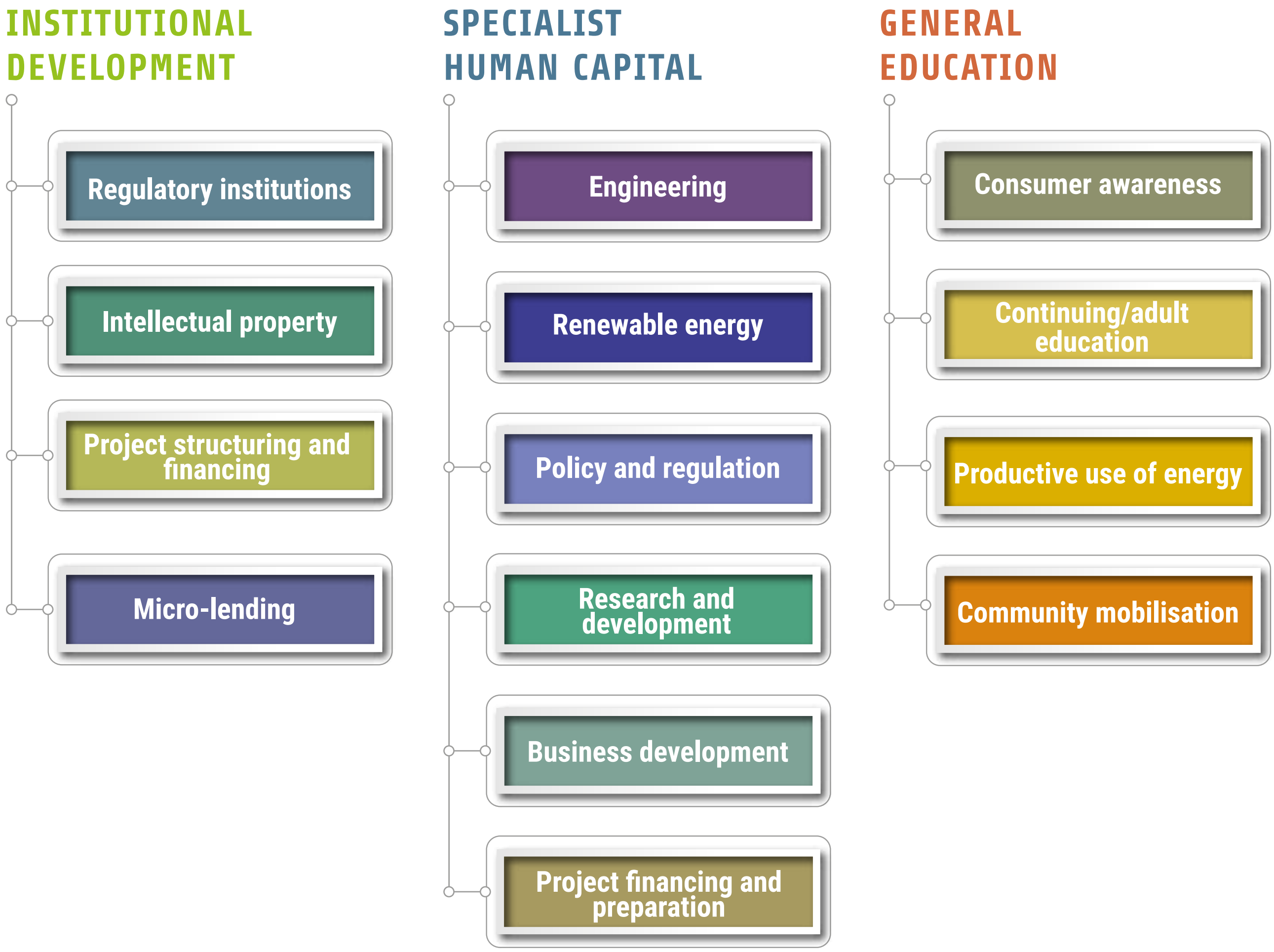
Figure 4: Areas for Micro-Grid Research



8.2 Human capital and institutional development

The deployment of micro and mini-grids has implications for human capital and institutional development at different levels, some of which are presented in Figure 5.

Figure 5: Capacity Development for Micro-Grids



An implementation strategy for mini-grid deployment should therefore, take cognizance of these capacity development needs and ensure that measures are put in place to address them.

8.3 Stakeholders and partners

Table 3 below lists main stakeholders directly involved in national policy implementation for micro-grids and their functions [20]:

Table 3: National Policy and Regulatory Stakeholders

Stakeholder	Functions
Ministry of Energy/Infrastructure	• Design rural electrification targets, strategy/vision and mission • Design and administer national energy policy and planning • Define rural electrification strategy (incl. the selection of operator models) • Administer public resource allocation • Initiate mini-grid regulatory and institutional framework
Treasury/Finance Ministry	• Provide rural electrification budget • Avail and coordinate grants and concessionary loans for rural electrification • Provide input on national electricity tariffs and subsidies • Determine stability of investment policy • Design and implement fiscal incentives
Energy regulator	• Facilitate the implementation rural electrification targets, vision and mission • Formulate and implement technical regulation (technical & service quality standards, main-grid interconnection requirements) • Formulate and implement economic regulation (tariffs, PPA, etc.) • Issue and monitor legal regulation (licensing, permit requirements) • Mediate disputes • Provide an advisory function to other entities
National environment agency	• Ensure mini-grid meets national environment standards • Issue licences as required • Monitor compliance with environmental regulations
Rural electrification agency	• Drive implementation of selected national operator models • In some cases, perform specific regulatory tasks delegated to the REA • Manage mini-grid project cycles, channel loans and grants for mini-grid projects (e.g. through a rural electrification fund) • Monitor and evaluate mini-grid projects • Development of electrification plans

Regional/local authority/ administration	• Support the identification of target areas • Authorise land use • Award building permits • Award resource utilisation permits, e.g. water rights • Promote mini-grid programmes • Facilitate contact with electricity users • Train and perform capacity building
Sector ministries linked to development, productive use and well-being (agriculture, education, health, water, sanitation, ICTs, trade, etc.)	• Advise on integration of productive use in micro-grid deployment • Integrate micro-grids in sector strategies and policies • Promote mini-grid programmes

These public-sector stakeholders need to work together with stakeholders from civil society, community organisations, private sector and academia in the planning and implementation of rural electrification and micro-grid programs.

- **Mini-grid deployment offers opportunities for research in a number of areas: battery storage, fuel sources: PV, biomass, wind, hydro, sustainable business models, policy and regulation.**
- **Implementation of micro-grid research should align with, and be informed by, the African Union Science Technology and Innovation Strategy for Africa (STISA).**
- **Micro-grids will require a critical mass of scientists, engineers and other specialists.**
- **Public-sector stakeholders need to work together with stakeholders from civil society, community organisations, private sector and academia in planning and implementation of rural electrification and micro-grid programmes.**

9

Recommendations for micro-grid implementation/adoption

Micro-grids are the cornerstone of sustainable, resilient power systems of the future. Just as witnessed in the mobile phone revolution, which completely democratised access to communication, it is expected that energy access might experience a similar revolution, thereby allowing easy and safe access to energy for all. Micro-grids present an economically feasible opportunity to accelerate access to electricity for remote communities on the vast continent of Africa. Key areas to be considered include capacity-building, enabling or supporting infrastructure, regulatory strengthening, research and development and stakeholder engagement.

The AU High Level Panel recommends that the AU, RECs, Member States and their partners should consider the following:

- Micro-grid implementation should be adapted and contextualised for Africa, taking into account factors such as site selection, the expected number of connections per site, the demand and willingness to pay and the expected return per connection. The Panel further recommends that contextualisation should be based on the prevailing natural resources to determine optimal selection of the underlying energy source (solar, wind, biomass or thermal).

- Skills and capacities for addressing under-served communities and the "informal sector" to support micro-grid implementation must be developed. This would mitigate against cases cited in some countries where micro-grid installations have suffered from not being properly operated or maintained, leaving communities unable to derive the intended benefits.

- Harmonised regulatory frameworks for micro-grid development which would focus, among other things, on investment laws and PPPs, sustainable tariff structures and cross-border interconnection must be put in place. The Panel further recommends the development of smart regulation leveraging on emerging trends in the use of ICTs.

- Micro-grid implementation should be based on multi-sectorial collaboration since interventions in agriculture, health, education, water and sanitation, social welfare and other sectors all have potential implications for energy projects.

- Stimulate bankability of micro-grid projects, a robust framework of incentives should be developed to stimulate private investment. The Panel further recommends the decentralisation of regulatory and support processes to local government level to enable mobilisation of domestic resources and faster, tailored responses to micro-grid deployment in under-served communities.

- Projects should aim to increase women's participation in the energy sector through procurement allocation policies, and by promoting employment of women in technical aspects of operation and maintenance. Projects should also encourage women to participate actively as business leaders and entrepreneurs, providing value-added productive services including producing and distributing new energy technologies and services. The Panel therefore recommends the promotion and strengthening of participation along entire micro-grid value chain by women and the youth.

- Higher education and research institutions should be supported to start implementing programmes that focus on renewable energy, micro-grids and associated generation, storage and distribution technologies. This should be employed simultaneously with the strengthening of intellectual property regimes, as well as increased awareness of how to license and use existing IP.

10

Conclusion

This report presents an overview of micro-grids as an emerging technology for application in Africa. Even though it can be argued that micro-grids have existed since the advent of electricity in the 19th century, today's idea of the micro-grid is a completely different concept which is underpinned by, and exploits recent developments in renewable energy technologies as well as information and communication technologies.

Apart from the technological innovations that will most certainly be delivered, there are other, perhaps even more critical issues that must be addressed to enable the deployment and up-scaling of micro-grids across Africa. These issues relate to creation of an enabling legal and regulatory environment, as well as effective community engagement to ensure that pertinent social and ethical issues are properly addressed in the development of micro-grids.

Micro-grids are the cornerstone of the sustainable, resilient power systems of the future. Just as witnessed in the mobile phone revolution, which completely democratised access to communication, it is expected that energy access might experience a similar revolution, allowing easy and safe access to energy for all. Micro-grids therefore, present an opportunity to accelerate access to electricity for remote communities on the vast continent of Africa.

References

[1] Academy of Science of South Africa (ASSAF), Turning Science On: Improving Access to Energy in sub-Saharan Africa, 6th Meeting of the African Science Academy Development Initiative, 7-10 November 2010

[2] Africa-EU Energy Partnership (2016), AEEP Energy Access Best Practices 2016, http://www.euei-pdf.org/en/aeep/thematic-work-streams/aeep-energy-access-best-practices-2016

[3] ABB (2015), ABB microgrid solution to boost renewable energy use by remote community in Kenya, Sept. 2, 2015, http://www.abb.co.in/cawp/seitp202/118e562a8edb8d40c1257eb400446361.aspx

[4] ABB (2015), Microgrids: A Primer for Policymakers, 2015, https://library.e.abb.com/public/3525a15fef5d47e28a8731bc45fb30f2/Microgrids_WhitePaper_92515_2.pdf

[5] ABB (no date), MicroGrid Plus control systems http://new.abb.com/microgrids/our-offering/microgrid-plus-system

[6] Active Power, Energy Storage for Distributed Energy Resources Deployments, http://www.activepower.com/en-US/documents/3803/wp118-energy-storage-for-microgrids

[7] AfDB (2013), The High Cost of Electricity Generation in Africa, Feb 18, 2013, https://www.afdb.org/en/blogs/afdb-championing-inclusive-growth-across-africa/post/the-high-cost-of-electricity-generation-in-africa-11496/

[8] AfDB (2016a),The New Deal on Energy for Africa: a transformative partnership to light up and power Africa by 2025, https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/Brochure_New_Deal_2_red.pdf

[9] AfDB (2017), Green Mini-Grids Africa Strategy, March 2017, http://greenminigrid.se4all-africa.org/uploads/gmg-africa-strategy.pdf

[10] African Forum for Utility Regulator - http://www.afurnet.org/en/about-afur/our-members

[11] Africa Progress Panel (2017), Lights Power Action: Electrifying Africa

[12] African Union (2014), Science, Technology and Innovation Strategy for Africa 2024, STISA-2024, African Union Commission, Addis Ababa, 2014

[13] African Union (2015) Agenda 2063 First Ten-Year Implementation Plan, http://www.nepad.org/resource/agenda-2063-first-ten-year-implementation-plan-2014-2023

[14] African Union(2016), Action Plan for Harmonized Regulatory Framework for the Electricity Market in Africa 2016

[15] Alliance for Rural Electrification. Powercorner/ENGIE - Ketumbeine mini-grid of 16 kW of PV panels, 45 kWh of Lithium batteries and a back-up genset (Tanzania). Retrieved from: https://www.ruralelec.org/project-case-studies/powercornerengie-ketumbeine-mini-grid-16-kw-pv-panels-45-kwh-lithium-batteries

[16] Alliance for Rural electrification, Hybrid Mini-Grids For Rural Electrification: Lessons Learned, Brussels, 2014

[17] Alstone P. et al (2011), Expanding Women's Role in Africa's Modern Off-Grid Lighting Market, October 2011

[18] Asmus, P., Cornelius, A., & Wheelock, C. (2009). Microgrids Islanded Power Grids and Distributed Generation for Community, Commercial, and Institutional Applications. Pike research.

[19] Avila, N., Carvallo, J. P., Shaw, B. and Kammen, D. M, The energy challenge in sub-Saharan Africa: A guide for advocates and policy makers: Part 1: Generating energy for sustainable and equitable development. Oxfam Research Backgrounder series (2017): https://www.oxfamamerica.org/static/media/files/oxfam-RAEL-energySSA-pt1.pdf

[20] Azuela G. A. (2015), Sustainable Energy for All Global Tracking Framework 2015, https://sustainabledevelopment.un.org/content/documents/13139Global%20Tracking%20Framework_World%20Bank.pdf

[21] Bardouille P. and D. Muench (2014), How a New Breed of Distributed Energy Services Companies can reach 500mm energy- poor customers within a decade, June 2014

[22] Baurzhan S. and Glenn P. Jenkins (2017), On-Grid Solar PV versus Diesel Electricity Generation in Sub-Saharan Africa: Economics and GHG Emissions Sustainability 2017, 9, 372; doi:10.3390/su9030372

[23] Bhatia, M., & Angelou, N. (2015). Beyond Connections Energy Access Redefined. Energy Sector Management Assistance Program, World Bank. https://www.esmap.org/node/55526

[24] Bourgeois T. et al, Community Micro-grids Smarter, Cleaner, Greener

[25] Boyd D., Power, Energy Storage, and the Decentralization of the Grid, Jan 17, 2017, https://graylinegroup.com/power-catalyst-overview/

[26] Burger A., Caterpillar Takes Equity Stake In Africa Microgrid Company Powerhive, Jan 26, 2016, http://microgridmedia.com/caterpillar-takes-equity-stake-in-africa-microgrid-company-powerhive/

[27] Colthorpe A. (2016), Tesvolt's 3MWh shipment to Mali could save villagers 80% of energy costs, November 22, 2016, https://www.energy-storage.news/news/tesvolts-3mwh-shipment-to-mali-could-save-villagers-80-of-energy-costs

[28] Colthorpe A. (2017), Vanadium-lithium hybrid systems would be 'optimal' for power and energy applications, 1 June 2017, https://www.energy-storage.news/news/vanadium-lithium-hybrid-systems-would-be-optimal-for-power-and-energy-appli

[29] Colthorpe A., (2017), South Africa's Eskom opens battery demo facility for 2000MW energy storage need, Energy Storage News, June 12, 2017, https://www.energy-storage.news/news/south-africas-eskom-opens-battery-demo-facility-for-2000mw-energy-storage-n

[30] DFID (2017), Integrating off-grid solutions into South Africa's Electrification Programme, May 2017

[31] Duby, S. (February 2017). Batteries are holding back the microgrid energy revolution in Africa. [Blog post]. Retrieved from http://www.pv-tech.org/guest-blog/batteries-are-holding-back-the-microgrid-energy-revolution-in-africa

[32] Economist Intelligence Unit (2016), POWER UP: Delivering Renewable Energy in Africa, 2016

[33] Energy 4 Impact & Inensus (2016), Green Mini-Grids in Sub-Saharan Africa: Analysis of Barriers to Growth and the Potential Role of the African Development Bank in Supporting the Sector, December 2016, African Development Bank.

[34] ESMAP. Renewable Energy Resource Mapping Initiative. http://www.esmap.org/RE_Mapping

[35] ESMAP Energy Storage Trends and Opportunities in Emerging Markets, 2017

[36] EUEI, Country Energy Assessment Tool, http://www.euei-pdf.org/en/seads/research-and-knowledge-sharing/euei-pdf-country-energy-assessment-tool

[37] Export-Import Bank Of India (2017), Working Paper No. 67, Power Sector In Africa: Prospect And Potential, May 2017

[38] FME, PESTLE analysis – strategic skills, 2013

[39] Franz M., J. Cloin, K. Wuropulos , Enabling Policies for addressing Climate Change and Energy Poverty through Renewable Energy Investments in Africa

[40] Franz M. et al (2014), The Mini-grid Policy Toolkit – Policy and Business Frameworks for Successful Mini-grid Roll-outs, European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF), Eschborn, Germany, 2014

[41] Franz M., D. Otieno, H. Taylor (2016), Africa-EU Energy Partnership comprehensive Mapping of Energy Initiatives and Programs in Africa, Eschborn, Germany, 2016,

[42] GET FiT (2016), GET FIT Expansion in Africa, Kampala, May 30 2016 - www.getfit-uganda.org/app/download/.../Claudia+Fersen+-+GET+FiT+Rollout.pdf

[43] GET FiT (2016) Status of Get Fit Roll out to other countries - http://www.getfit-reports.com/2016/outlook/status-of-get-fit-roll-out-to-other-countries/

[44] Gollwitzer, L. (2014) Community-based Micro Grids: A Common Property Resource Problem, STEPS Working Paper 68, Brighton: STEPS Centre

[45] Golumbeanu, R. and Barnes, D. (2013) Connection charges and electricity access in Sub-Saharan Africa; the World Bank Africa region sustainable development network. https://openknowledge.worldbank.org/bitstream/handle/10986/15871/WPS6511.pdf?sequence=1

[46] Groh, S., Philipp, D., Lasch, B. E., & Kirchhoff, H. (2015). Swarm Electrification: Investigating a Paradigm Shift Through the Building of Microgrids Bottom-up. In Decentralized Solutions for Developing Economies (pp. 3-22). Springer International Publishing.

[47] Gupta A., Where micro-grids, emerging markets and flow batteries intersect, March 10, 2016, https://www.energy-storage.news/blogs/where-micro-grids-emerging-markets-and-flow-batteries-intersect

[48] Harrington K., New Smart Solar Microgrids Speed Up Rural Electrification in Kenya, March 2, 2016, https://www.aiche.org/chenected/2016/02/new-smart-solar-microgrids-speed-rural-electrification-kenya

[49] Hebner R., Nanogrids, Microgrids, and Big Data: The Future of the Power Grid, IEEE Spectrum , Mar 2017 http://spectrum.ieee.org/energy/renewables/nanogrids-microgrids-and-big-data-the-future-of-the-power-grid

[50] Hempling S., Preparing for Microgrids: Legal and Economic Principles, Maryland Resiliency Through Microgrids Task Force, March 10, 2014, http://www.scotthemplinglaw.com/files/pdf/preparing_for_microgrids_hempling_0314.pdf

[51] IEA (International Energy Agency) (2012) World Energy Outlook 2012. Paris: International Energy Agency

[52] IEA (2014), Africa Energy Outlook - A Focus on Energy Prospects in Sub-Saharan Africa, OECD, Paris 2014

[53] IEA (2016) Key Renewables Trends: excerpts from Renewables Information (2016 edition), 2016

[54] IRENA (2012), IOREC 2012 International Off-Grid Renewable Energy Conference Key Findings and Recommendations

[55] IRENA (2014), Renewable Power Generation Costs in 2014

[56] IRENA (2015), Off-Grid Renewable Energy Systems: Status and Methodological Issues, 2015

[57] IRENA (2015), Battery Storage for Renewables: Market Status and Technology Outlook 2015, http://www.irena.org/documentdownloads/publications/irena_battery_storage_report_2015.pdf

[58] Jones A. (2016), Electrifying rural Africa with solar-plus-storage, Energy Storage News, March 26, 2015, https://www.energy-storage.news/blogs/electrifying-rural-africa-with-solar-plus-storage

[59] Kamwanja L. (2017) Personal communication

[60] Kimmins, J. P. (2001). The ethics of energy: a framework for action. UNESCO. Retrieved from: http://unesdoc.unesco.org/images/0012/001235/123511eo.pdf

[61] Lazar, J. and Gonzalez, W. (2015). Smart Rate Design for a Smart Future. Montpelier, VT: Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/7680

[62] Lee K. et al (2016), Electrification for "Under Grid" households in Rural Kenya, Development Engineering, Volume 1, June 2016, Pages 26-35.

[63] Léna, G. (2013). Rural Electrification with PV Hybrid Systems: Overview and Recommendations for Further Development. Report IEA-PVPS T9-13:2013. IEA.

[64] Lennon A. (2017) UN and EU fund Solar century to build solar mini-grid projects in rural East Africa, July 19, 2017, https://www.energy-storage.news/news/un-and-eu-fund-solarcentury-to-build-solar-mini-grid-projects-in-rural-east

[65] Mama C. (2016), Africa and the Policy Push for Mini-grid growth, March 14, 2016, http://microgridmedia.com/africa-policy-push-mini-grid-growth/

[66] Mama C. (2016), Mobile Phone Adoption In Africa Can Provide Tools, Demand, and Lessons for Off-Grid Electrification, April 7, 2016, http://microgridmedia.com/mobile-phone-adoption-in-africa-provides-tools-demand-and-lessons-for-off-grid-electrification/

[67] Manetsgruber D. et al., Risk Management for Mini-Grids: A new approach to guide mini-grid deployment

[68] Masebinu S.O., et al. A Review on Battery Technologies for Electrical Energy Storage, Proceedings of the International Conference on Industrial Engineering and Operations Management, Rabat, Morocco, April 11-13, 2017, http://ieomsociety.org/ieom2017/papers/581.pdf

[69] McMahon J, Batteries Will Do To Energy What Cell phones Did To Telecom: Advanced Microgrid & Tesla, Forbes.com, Aug 24, 2015, https://www.forbes.com/forbes/welcome/?toURL=https://www.forbes.com/sites/jeffmcmahon/2015/08/24/batteries-will-do-to-energy-what-cellphones-did-to-telecom-advanced-microgrid-tesla/&refURL=&referrer=#24dc953a53be

[70] Microgrid Institute (no date), About Microgrids, http://www.microgridinstitute.org/about-microgrids.html

[71] Microgrid News (2015), What is a Microgrid? There's More Than One Microgrid Definition, 09/04/2015, http://microgridmedia.com/what-is-a-microgrid-more-than-one-microgrid-definition/

[72] Microgrid Projects (2017), Types of Microgrids, Jan 3, 2017, http://microgridprojects.com/types-of-microgrids/

[73] Mulanje Electricity Generation Agency (MEGA) http://www.mega.mw/

[74] NEPAD Agency, Programme for Infrastructure Development in Africa, (PIDA), http://www.nepad.org/programme/programme-infrastructure-development-africa-pida

[75] O'Connor J. (2016) Solar City, Tesla, and Virunga - Building Solar Micro Grids for the guardians of Africa's oldest and most biodiverse national park, August 22, 2016, https://medium.com/solar-microgrid/solarcity-tesla-and-virunga-6008526f4a53

[76] O'Connor J. (2017), Battery Showdown: Lead-Acid vs. Lithium-Ion : which is the best battery for an off grid energy system?, Jan 23, 2017, https://medium.com/solar-microgrid/battery-showdown-lead-acid-vs-lithium-ion-1d37a1998287

[77] OECD (2015), Projected Costs of Generating Electricity 2015 Edition, September 2015

[78] Ola D. (2017) USTDA backs tender request for 25MW hybrid solar-storage in Sierra Leone , June 12, 2017, https://www.energy-storage.news/news/ustda-backs-tender-request-for-25mw-hybrid-solar-storage-in-sierra-leone

[79] Powermag (2016), East Africa's Largest Solar Plant Starts Operations, Dec 12, 2016, http://www.powermag.com/press-releases/east-africas-largest-solar-plant-starts-operations/

[80] Practical Action (2016), Developing Mini-grids in Zambia How to build sustainable and scalable business models?, http://www.enea-consulting.com/wp-content/uploads/2016/02/ENEA-Practical-Action-Developing-mini-grids-in-Zambia.pdf

[81] REN 21 (2016), Renewables 2016: Global Status Report, Paris 2016

[82] Rogner, H. H., et al. (2000). World Energy Assessment: Energy and the challenge of sustainability. World Energy Assessment: Energy and the Challenge of Sustainability. UNDP/UN-DESA/World Energy Council, NY, 135-171

[83] Ryan C. (2017), BBOXX to provide Togo with 300,000 solar home solutions, July 18, 2017, https://www.energy-storage.news/news/bboxx-to-provide-togo-with-300000-solar-home-solutions

[84] SE4All, SE4All Africa Hub Country Data, https://www.se4all-africa.org/se4all-in-africa/country-data/

[85] SE4All, Green Mini-Grid Market Development Program (GMG MDP), SE4All Africa Hub, https://www.se4all-africa.org/se4all-in-africa/regional-initiatives/green-mini-grids/

[86] Singh S.N., V. S. Prathiba, and Nikhil Katiki , Smart Micro Grid Model for Rural India , 2nd International conference on Innovative Engineering Technologies (ICIET'2015) August 7-8, 2015 Bangkok (Thailand) , http://iieng.org/images/proceedings_pdf/6478E0815022.pdf

[87] Tenenbaum, B., Greacen, C., Siyambalapitiya, T., & Knuckles, J. (2014). From the bottom up: how small power producers and mini-grids can deliver electrification and renewable energy in Africa. World Bank Publications.

[88] UNDESA (2015), World Population Prospects: The 2015 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP.241.

[89] UNECA Africa Regional Integration Index Report 2016

[90] UN-Energy/Africa Energy for Sustainable Development: Policy Options for Africa, Commission on Sustainable Development 2015, New York, 2015

[91] UNICEF Report – Generation 2030|Africa -https://www.unicef.org/publications/files/UNICEF_Africa_Generation_2030_en_11Aug.pdf

[92] UNIDO (no date), Renewable Energy Project Portfolio

[93] UNIDO (2005), Sustainable energy regulation and policymaking for Africa, Geneva, 2005

[94] UNIDO (2017), Renewable energy-based mini-grids: the UNIDO experience, Department of Policy, Research and Statistics Working Paper 1/2017, Geneva, 2017,

[95] USAID (no date), Power Africa: Beyond The Grid Fund For Zambia, Energy Access for One Million Zambians -http://www.sida.se/contentassets/f8089eb605cc4b1daab354cbd3476a8d/beyond_the_grid_fund_zambia_brochure.pdf

[96] USAID (no date), Power Africa: Beyond the Grid Partner Commitments, https://www.usaid.gov/powerafrica/beyondthegrid

[97] WEF (2017), The Africa Competitiveness Report 2017: Addressing Africa's Demographic Dividend, Geneva, 2017

[98] Wiemann M. and D. Lecoque, Sustainable Energy for All High Impact Opportunity mapping of mapping of clean energy mini-grid support providers and programmes, 2015

[99] Willis B., Fraunhofer ISE developing technologies for Africa-Europe 'super grid', Energy Storage News, March 2, 2014, https://www.energy-storage.news/news/fraunhofer-ise-developing-technologies-for-africa-europe-super-grid

[100] WIPO , WIPO Green Portal (https://www3.wipo.int/wipogreen/en/)

NEPAD

230, 15th Road, Randjespark

Midrand, Gauteng

South Africa

Telephone +27 (0) 11 256 3600

www.nepad.org

African Union

NEPAD
TRANSFORMING AFRICA