

Kumar V., Sampath; Prasad, Jagdish; Samikannu, Ravi

Article

Barriers to implementation of smart grids and virtual power plant in sub-saharan region-focus Botswana

Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Kumar V., Sampath; Prasad, Jagdish; Samikannu, Ravi (2018) : Barriers to implementation of smart grids and virtual power plant in sub-saharan region-focus Botswana, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 4, pp. 119-128, <https://doi.org/10.1016/j.egy.2018.02.001>

This Version is available at:

<https://hdl.handle.net/10419/187899>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

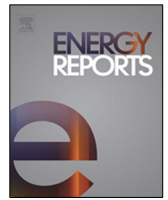
Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/>



Research paper

Barriers to implementation of smart grids and virtual power plant in sub-saharan region—focus Botswana

Sampath Kumar V. ^{a,*}, Jagdish Prasad ^b, Ravi Samikannu ^c

^a Amity Business School, Amity University Rajasthan, Jaipur, Rajasthan, India

^b Amity School of Applied Sciences, Amity University Rajasthan, Amity Education Valley, Kant Kalwar, NH-11C, Jaipur-Delhi Highway, Jaipur, Rajasthan, 303007, India

^c Department of Electrical Engineering, Botswana International University of Science and Technology (BIUST), Private bag 16, Palapye, Botswana

HIGHLIGHTS

- Smart Mini Grid Model and Smart system design for segregating loads.
- Feeder segregation for residential and industrial load with allowance for demand growth.
- Grid tied inverter can be used to ensure integration to the central grid.
- Ensure Public–Private Partnership.
- Optimally spread framework across the chain guarding and minimizing the investors from risk needs to be implemented.

ARTICLE INFO

Article history:

Received 7 July 2017

Received in revised form 19 October 2017

Accepted 16 February 2018

Keywords:

Smart mini grid
VPP

T&D losses

DER's

Vision 2030

Vision 2016

ABSTRACT

If Vision 2030 of UN to provide electricity to everyone be achieved, it is essential that over 40% of Botswana's population living without electricity be looked into from different perspectives and new models. In all smart grid models, it is often emphasized that the residents and the consumers play a vital role in electricity management of Supply and Demand and are expected to be co-producers of electricity. This article looks into the various challenges and success that Botswana has achieved in terms of implementing new technologies and what needs to be done to provide electricity to the rest of the 40% of the community without electricity. This article goes on to describe how a small smart mini grid could serve as a purpose to aid in village development.

© 2018 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

As of 2016, over 5 million people across the globe have been living without electricity, and this poses a significant challenge to many developing nations. The grid infrastructure across many countries still operate in the same manner, and not much has changed in its outlook. The same holds good for the generation part of the energy. One of the primary reason for the above is the inability of the Governments to focus on advanced technologies (Fangxing, Fran et al., 2010; Clement and Kevin, n.d.). According to

WHO, global health observatory, WHO, Global Health Observatory (n.d.). “Earth's population has become abundant, but the number of world inhabitants living in cities has not surpassed people living by the countryside until recent years”. Therefore, the demand for energy is expected to grow significantly and considering the limited resources, it becomes a bottleneck on the fossil resources and depleting natural resources. It is therefore essential to tap the renewable and alternative energy resources to lower the impact on the planet (Rodríguez-Molina et al., 2014).

The entire region of Sub-Saharan insurmountable challenges in the form Energy and Climate change and the Socio-Economic growth of the region remains in its ability to harness energy, which is critical to its growth. As indicated in Fig. 1, lack of access to critical commodity, ‘electricity’ is an essential determinant of poverty in Sub-Saharan Africa (Deichmann et al., 2011). According to world energy outlook report 2014, Sub-Saharan Africa has more than 620 million people without access to electricity, that is nearly half of

* Corresponding author.

E-mail addresses: sampathkumaris123@gmail.com, sampathkumaris123@outlook.com (Sampath Kumar V), jprasad@jpr.amity.edu (J. Prasad), drraviee@gmail.com (R. Samikannu).

¹ Currently Affiliated to Botho University, PO Box 501564, Kgale KO, Near Game City, Gaborone, Botswana.

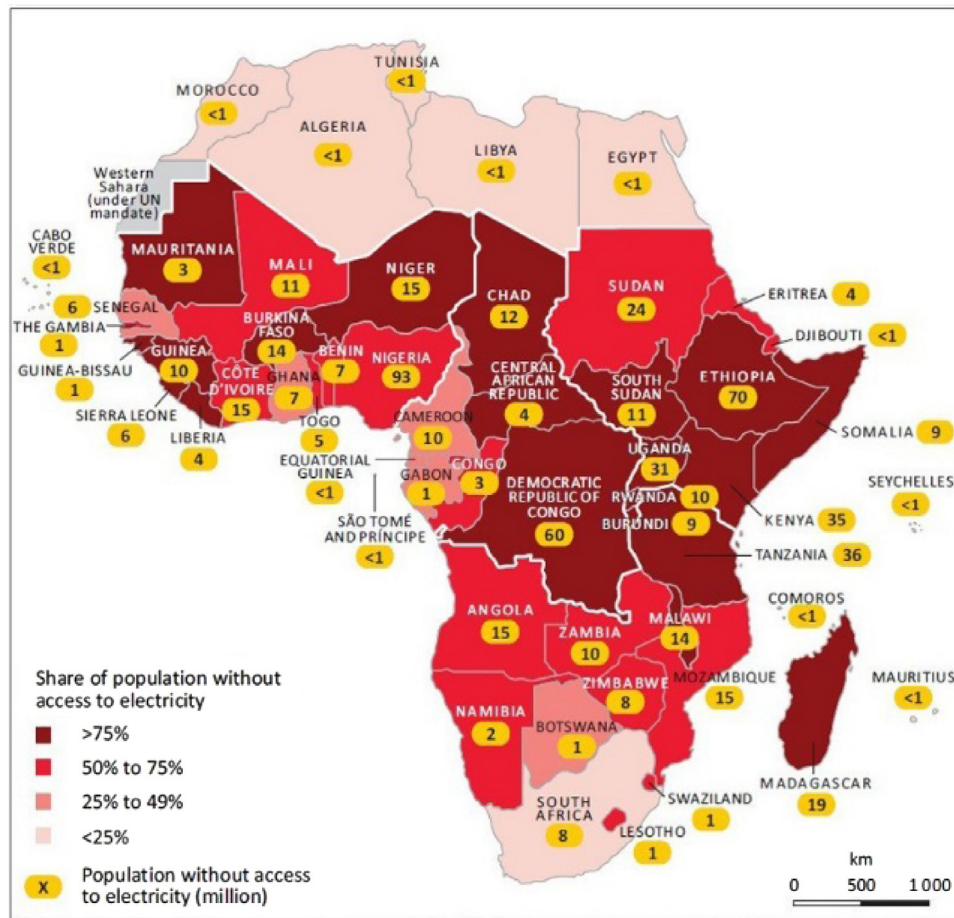


Fig. 1. Population without access to electricity.
Source: IEA (2014a, b).

total global figure and is rising day by day due to rapid population growth. Though the overall access to electricity rate for the region improved to 23% in 2012, the access to electricity remains a distant dream for many (IEA, 2014a, b). UN 2030 agenda for sustainable development reports includes an agenda on energy. As adopted it envisions to eradicate global energy poverty by providing access to affordable, reliable and sustainable energy to all (UN, 2015). It is essential for the region to attain 100% electricity access to its people while mitigating the impact of climate change and reducing the carbon print across the region. Technologies like renewable energy system for generating electricity storage has far-reaching socio-economic benefits. It is essential that the Governments play a pivotal role in encouraging the use of renewable energy sources to develop its energy infrastructure (Hoeven, 2014). In Sub-Saharan energy, the report estimates 423 Twh in 2010 including self-generation, such as diesel generators (Castellano et al., 2015). The International Energy Agency (IEA) expects the total demand for electricity in Africa to increase at an average rate of 4% a year until 2040 (IEA, 2014a, b). There has also been increasing attention on poverty alleviation through energy access improvement among international organizations in the energy field (Kanagawa and Nakata, 2008). To meet this growing demand in the region, it is essential that the nations must double up significantly and expand their generation capacity. While upgrading it is essential that the infrastructure regarding the transmission and distribution network also be upgraded with latest technologies. To achieve the vision of UN, it is critical that the rural areas in the Sub-Saharan African region be targeted for rural electrification. Academicians define rural electrification as a percentage of rural population

with access to electricity (Paul, 2011; Trotter, 2016). Kanagawa and Nakata (2008) highlight a critical factor for increasing access to rural electrification by stressing the importance of higher literacy rates by upgrading school and higher education. Within Sub-Saharan Africa, there is a great disparity that exists in both rural electrification and urban electrification (Trotter, 2016). This inequality is critical to understanding when electrification takes place in the areas.

Except for South Africa in Sub-Saharan Africa, the rest of the Nations rank last among global regions in energy consumption per capita (DHS, 2009). While many rural areas and villages have practically no access to electricity except for the power relatively owned by affordable entities, it is critical to understand the reason for the areas starved. In understanding the comparison between the rest of the globe, (Latin America and the Caribbean) the urban and rural distributions for the Sub-Saharan Africa is relatively decidedly less, in fact so low that they hardly overlap (Deichmann et al., 2011). The key to solving the energy crises and the climate challenges in the region is through renewable energy. However, the limiting factor is useful policy frameworks, technical, financing and education to its clients and citizens and to enable the region to develop these resources (Avila et al., 2017).

The Department of Energy Affairs (EAD) within the Ministry of Minerals, Energy & Water (MMEWR) leads the country's national energy policy in Botswana. MMEWR through Botswana Power Corporation (BPC) is the main decision maker for the power generation, transmission, and distribution. EAD administers the Electricity Supply Act, which latest amendment promotes IPP's participation (USAID, 2016) to achieve security supply in power

generation. A UN statistical database on energy statistics in Botswana portrays that the demand has been increasing continuously from 2009. This growing demand for energy demands that new opportunities be explored and alternate sources of energy be developed. Botswana's supply security in the year 2013 was highly dependent on internal generation since there were no firm power imports before the year the country was roughly importing close to about 80% of Nations power supply from Eskom in South Africa. BPC installed additional capacity of 450 MW in Marupule B coal-fired power plant (USAID, 2016). However, to meet the growing demand, the contract to Eskom was extended on a non-firm basis for 300 MW up to December 2015. Utilization factors and study pattern, show that 1509 GWh, amounting to 42% of country's requirement was imported as compared to previous years. The Power demand was imported from "Eskom, *Electricidade de Mozambique (EDM)*, *NamPower of Namibia*, *ZESCO of Zambia* and the *Day Ahead Market (DAM) of the Southern African Power Pool (SAPP)*". Japanese-funded Solar Photovoltaic power plant that was commissioned during 2012 could not offer much hope to the growing demand on the energy sector in the country (Botswana Power Corporation, 2015) (Source Data: BPC Annual Report 2015). To mitigate the national demand average of 550 MW, the BPC on average imports up to 150 MW from South Africa, but this import does not prevent, load shedding. In 2013 two emergency diesel facilities, 70 MW at Matshelegabedi and 90 MW at Orapa, were installed to avoid such outages. Morupule B is also starting expansion in 2016 (USAID, 2016) to add another 300 MW by 2020. Based on 2013 data, Botswana's national electrification rate reached 66% (54% in rural areas, 65% in urban one), but 1 million people still lack access to electricity (USAID, 2016) as shown in Fig. 1.

This paper primarily highlights the challenges in Botswana; the Sub-Saharan region faces regarding energy crises. It highlights importance on well-known emerging concepts, systems and technologies of Smart Grid and how it can contribute to meet the growing demand of electricity needs of the Sub-Saharan Africa. This paper argues how the Smart Grid advances could accelerate rural and urban electrification time frames, improving service delivery while minimizing costs, environmental impact and reducing carbon footprint and also how smart grids can be a source of an improvement in the socio-economic livelihood of the consumers. The organization of the paper is as follows: the second section presents the previous research works in the area, Section 3 portrays analytical framework followed while Section 4 presents the insights from the demonstration activity; Section 5 offers discussion, recommendations, while Section 6 contains the concluding remarks (see Fig. 2).

2. Analytical research framework

The primary assertion for this research was, the growing insecurity in the distribution of the electricity, and if they need to compete with the traditional grid electrification, what are the suppositions for alternate means of generating and distributing energy. The analytical framework makes an in-depth analysis of the existing grid infrastructure in Botswana and elsewhere and analysis the need for expanding the network in through DER's.

2.1. Findings and challenges

According to IEA (2014a, b), electricity scarcity in the region has crippled the region's economic growth which in turn has had a ripple effect on health, education and sustainable growth (IEA, 2014a, b).

Bueno et al. observe that many democratic countries in the Sub-Saharan region perform better at providing public amenities (Siverson et al., 2003). However, this has not been a contributing

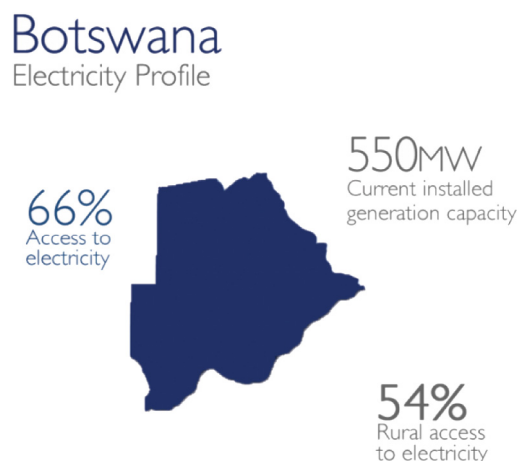


Fig. 2. Botswana energy profile. Source: USAID (2016).

factor to the electrification needs of the rural areas. The fact that 60% of them lie in rural areas concur increased cross-sectional imbalance in rural electrification and inequality regarding political, economic and demographic factors (Diaz-Cayeros et al., 2013; Kroth, 2014; Lake and Baum, 2001; Trotter, 2016). Research studies indicate that though there is significant progress in electrification around the world, the success of providing the electricity remains and rests with the commitment from Government and local Institutions. One significant barrier to this is the financial support on the part of institutions. It is believed that there could be a substantial improvement in the access to clean energy with proper policy frameworks, enforcement of appropriate technical standards, standard operational metrics, financial support, research and development and stakeholder relations (Palit and Chaurey, 2011; Bhattacharyya and Palit, 2016). Capital and operating costs take the major chunk of fixed costs linked to Transmission and distribution. Although there are no significant growths in economic scale due to the hardware cost, it poses significant risks when integrating delivery tasks.

It has been argued that urban electrification has a positive impact on GDP while the same has been disputed for the rural electrification. The primary reason that it was attributed to was that rural areas need more capital due to economic scale differences. This implied that it was making a much smaller business case when it came to deciding on rural vs. urban (Paul, 2011). In his book, Herbst points out numerous challenges in the form of infrastructure investments in the sparsely populated African nations, like Botswana (Herbst, 2002). According to Foster et al., about 81% of infrastructure investment in the power sector was from domestic sources (Foster and Cecilia, 2010). Quantitative research suggests a positive relationship between domestic savings and domestic investment in general in sub-Saharan Africa (Trotter, 2016).

IEA estimates that to achieve the target of providing electricity to everyone by 2030 will require additional power sector investment of USD 33 billion per annum on average for Sub-Saharan Africa alone (UNEP, ILO, IOE, and ITUC, 2008). IEA in their report indicates that an investment of \$890 billion is needed between 2011–2030 for electrification alone excluding the investments required for maintaining the grid and other infrastructural structures (IEA, 2014a, b; Bazilian et al., 2010a; Bhattacharyya and Palit, 2016). One critical challenge that Botswana as a country is experiencing is similar to many developing nations and is not unique to the nation that is, how to electrify using the existing grid network? The solution to this problem could like in breaking down the problem

into smaller bits and pieces by adopting to distributed generation. Efficiency, demand-side management, optimal generation, improved grid transmission is essential and critical to achieving this goal and to minimize the volume of investments needed. Thus to meet the targets or vision of UN 2030 for providing electricity to all, remains a challenge and there is an urgent need to fast-track it in Botswana.

The critical energy infrastructure in Sub-Saharan Africa is weak and unreliable in terms of T&D as compared to South Africa, which is slightly faring better. Bello et al. (2013) in this case study in South Africa indicates that the electricity generated is not sufficient to meet the increasing demand. In a similar scenario with South Africa, the energy generated in Sub-Saharan Region is not enough to meet the growing demand and fails to meet the peak demand. It is essential that the Sub-Saharan Africa unite different energy infrastructure across nations to establish proper interconnectivity standards of renewable energy sources for enhanced flexibility, information flow, improved system, control, demand-side management, demand response, which is critical for development in the region (Kempener et al., 2013; Ma et al., 2016).

The delivery of power over long distances at ultra-high voltages has its own shortcomings (Knoepfel, 1996; Bahrman and Johnson, 2007; Oudalov and Reza, 2007; Davis, 1999; Sebitosi and Okou, 2010) in the form technical, economic and commodity loss, which again poses a question on is the how efficient and economical is 'transmission' through the grids. The lack of systematic planning for the power sector has resulted in a system with high transmission and distribution losses (Avila et al., 2017). It is estimated that about 46% of the generated electricity is lost in transmission across rural Africa (Ma et al., 2016). These losses increase the generation capacity that is required to meet load, making centralized generation uneconomical, exposing power companies to large financial risks, and increasing end-user tariffs (Castellano et al., 2015). Therefore it is essential that the losses in T&D be minimized. Though technically, a loss in the T&D has to be compensated by the increase in electricity generation, alternate means of breaking down the grid losses needs to be identified. Bazilian et al. proposed that the "current and emerging smart grid concepts, systems make an important contribution to improving equitable and just access to electricity services in Sub-Saharan Africa" (Bazilian et al., 2010b, 2013; Birol, 2010). Adding to this is the age-old technology that is predominantly adapted by many electric companies across the globe and Botswana as a country is no exception. Many of the transmission and distribution lines are old and need to be revamped. BPC, the commodity provider, carries power over long distances in Botswana. One reason to it is that majority of its citizens are from rural areas. This inherent challenge both technically and economic feasibility for long distance transmission calls for revamp of the adapted technology in both generation and grids. One way to break this jinx is to go "SMART" and achieve its goal of providing electricity to everyone in the country. As indicated by Gellings in his book, smart means an "intelligent use of Communications, Computational ability, efficiency, control with technology to enhance the overall functionality of the delivery system" (Clark, 2009).

2.2. Renewable energy

Climate plays a very vital role in the selection of renewable energy source. Botswana's climate is shown in Fig. 3. The data was based on a record from 1991–2015 (Meteoblue, n.d.). The usage of the renewable systems defines electrification paradigm. The use of the system is different and varies depending on the location. While the primary goal has two factors, one to meet the local needs and the other sustainability in the form of regular supply of electricity (Pillota et al., 2017).

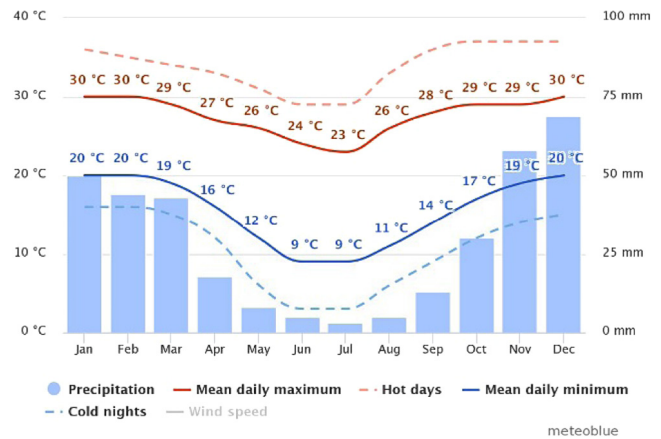


Fig. 3. Climate profile of Botswana (Meteoblue, n.d.).

The complex problem of energy crises in the form of topography, socio-economic conditions, poverty, presents immense opportunities in various renewable energy resources as a form and means of energy production and sustainability, ensuring regular income. This opportunity can be utilized to design low-fuel, low-carbon power systems based on the wind, geothermal, and solar technologies and to use responsive and efficient demand management strategies. The region is home to abundant fossil and renewable energy sources. The technical potential for generation capacity is estimated at 10,000 GW of solar power, 350 GW of hydroelectricity, and 400 GW of natural gas, totaling more than 11,000 GW (Avila et al., 2017).

Exploiting renewable energy resources in the region will require a revamp. Although the region has abundant natural resources in the form of Wind, Solar, geothermal, wave, the resources are unevenly distributed geographically. To tap this vast potential and supply clean, and low-cost energy will require collaboration and cooperation among nations. For example, the energy generated from PV arrays in countries like Botswana, Zimbabwe can be used along with countries producing energy from the wind, geothermal, hydropower like South Africa, DRC, Malawi thus balancing regional grids. Since many of the potential renewable zones are close to existing transmission grids, the cost of T&D will be minimized. By exploiting these synergies, the potential conflicts that may arise can thus be reduced. The wind and solar generation sites can be co-located to reduce costs, maximize transmission efficiencies, and minimize ecological impacts (Kempener et al., 2013).

Botswana's energy challenges include rapidly growing demands for electricity, untapped solar potential. Other forms of non-conventional energy sources, like Solar, Wind, Geothermal, have largely remained untapped entirely (IEA, 2012). Botswana receives approximately 3200 h of sunshine per year and has high insulation on a horizontal surface of 21MJ/M². The average daylight hours in Botswana ranges from 9.9 h in summer to 8.2 h in winter. This amounts to one of the highest insulation rates in the world. The horizontal irradiation for Botswana is shown in Fig. 4 (Solar GIS, n.d.). Therefore, it is paramount on the country's energy agenda to increase access to electricity in remote areas with a particular focus on utilizing renewable energy resources. The wind potential in Botswana is moderate, and the average wind speed at a 100 m height is 5–7 m/s based on a 30-year data from ECMWF. This is comparatively low compared to South Africa. Biomass mainly charcoal and firewood continue to be a significant source of energy in Botswana in rural areas. The vast cattle population in Botswana indicates that there is a vast potential for tapping this resource as biogas (IEA, 2012).

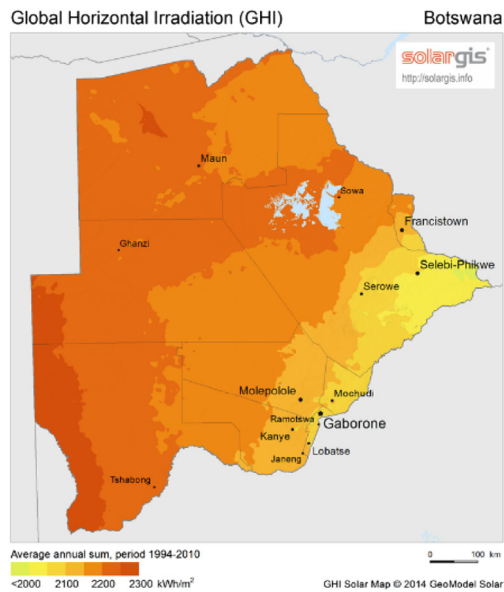


Fig. 4. Global horizontal irradiation.

2.3. Smart grids, microgrids and VPP technology

Smart Grid is an advanced modernized holistic concept where a broad range of ICT resources is put to use to reduce electricity wastage and energy costs. Smart Grid facilitates efficient two-way delivery system, reliable end-to-end, intelligent from source to sink, smart transmission and distribution through the integration of renewable energy sources. The combined power of IT + Power (Smart Grid) enables real-time monitoring and control of power system. It helps in reduction of demand response and demand side management, AT&C losses, power quality management, outage management, smart home energy system. The fact that the smart technologies are expensive, when it comes to implementation on the budget side, which remains a bottleneck currently, there are other factors that need to be taken into account especially on the associated risks of delivery. These risks can be mitigated by effectively by the policymakers and regulators by efficiently implementing advanced digital technologies and seeking economies of scale.

A microgrid is a cluster of local distributed energy resources (Abdolarasol et al., 2017). Its flexibility with loads aid in operation modes and can be operated within the grid or islanded fashion. It is typically connected to low voltage lines but can also be operated on a medium scale. The connected microgrids appear as one node, generating or consuming power from the grid. Microgrids which operate in an isolated mode will require energy storage devices and loads are often differentiated in classes (Buhler, 2010).

One of the areas that can help improve the scenario is Virtual Power Plant. Virtual plant—As its name implies, does not exist in the concrete-and-turbine sense. Instead, it is a collection of DER's. It uses the smart-grid infrastructure to tie together small, disparate energy resources as if they were a single generator. Just about any energy source can be linked up as a DER. Moreover, the energy that is (Kumagai, 2012) used can also contribute to a virtual power, not plant's capacity. VPPs can be termed as a manifestation of transactive energy implementing new technologies like demand response, solar photovoltaic systems, advanced batteries, electric vehicles thereby transforming consumers actively to participants in delivering services. VPP relies on software and smart grids (Asmus, 2017; VPP, 2015; Sampath et al., 2017). While virtual power plants act as pools of autonomous generation units for producing

both heat and electricity, the solar cells can only be provided to the consumers locally. In principle, virtual power plants are suited for long-distance transfer (Franke et al., 2012).

With the development of Smart Grid, VPP and microgrids, many challenges can be controlled to a greater extent, this not only will improve the efficiency of our distribution system, since in this model the consumers become the producers. This will also add on to the sustainable economic development of the common man. By ensuring regular income in the form of return for the energy supplied back to the grid, there will be fewer blackouts, thus ensuring grids that it will provide higher quality and reliable power supply Oliver et al. argues on how smart grid technologies enable policy-makers and communities to manage enduring energy policy concerns successfully. They then define what 'smart' energy technologies, grids and policies mean, and evaluate how the smart grid can enable policy-makers to respond to an emerging energy trend in what they term three pillars or triad of a sustainable economy by terming it energy 'trilemma' (Oliver and Sovacool, 2017).

3. Barriers in smart grids, microgrids and VPP

3.0. Technical challenges

Renewable energy comes in different forms and sizes. Notably, the wind and solar dependent factors on climate and is ever fluctuating. As a source of energy, it is critical that they must meet the required demand at all times and hence are required to ensure that the electricity demand is available to absorb this variability. With the advent of Smart grids, the challenges in the form of technical and non-technical are imminent. DER's represent a new model and are usually small-scale systems privately owned and operated. Since most grids still operate traditionally, it causes speculations among the different operators to connect and accommodate these smaller DG's to the grid citing instability, safety, operational difficulties, pricing agreement disputes. It is a known fact that most of the renewable energy installations require high investment initially but very low running and maintenance costs. This "cost-effective" solution on a lifecycle basis, in developing countries, is just not cost-effective and affordable and do not have access due to insufficient capital investment in renewables. However, these challenges can be overcome (Wu et al., 2015). Renewable energy resources like wind and solar are fluctuating resource as a form of energy. With irregularities in them either the form of slow wind or obscure clouds in the sun, the production in output will drop. This will result in electricity operators scrambling for other sources to meet demand and supply. Under normal conditions, a small fraction of total electricity fluctuations is usually manageable, however, when there is a significant fraction, reliability becomes increasingly challenging (Kempener et al., 2013).

The off-grid systems pose challenges in its way. All renewable energy systems come at a cost. The upfront investment costs are high. While comparing a small solar system with that of a diesel system for the same amount of generated power, the investment in the diesel system is far too low. However, it is worthwhile to note that the system requires a lot of periodical maintenance unlike a solar PV system except the storage battery pack for the system and battery packs be expensive. The climate plays a vital role in renewable energy systems. Extensive research in the area indicates that the performance of the PV system decreases as the temperature rises. This could also negatively impact on the lifespan of the PV system. Since all the PV systems use batteries as a storage pack, it is essential to protect the battery pack, since it is directly temperature dependent. An ideal climate is essential for any PV operation, in short, the climate should be cool and sunny at the same time. Excessive heat is a problem to any PV system, and Botswana is hot. In the case of PV arrays for large loads, space plays

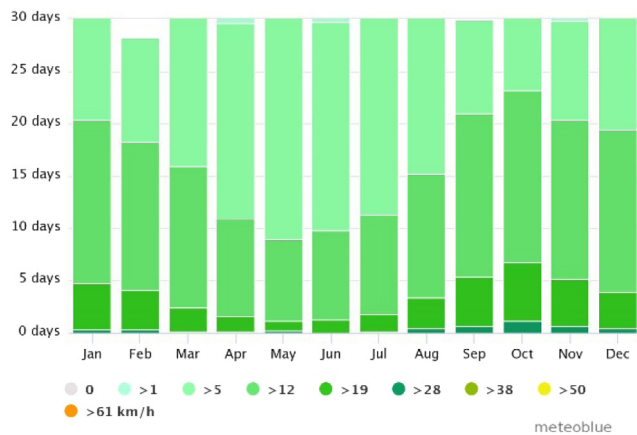


Fig. 5. Wind profile for Botswana (Meteoblue, n.d.).

a role in determining the generated output. A restricted space will be a barrier to hosting large load capacity systems. In the case of wind turbines, it is essential that the wind speeds be negligible for the turbine to spin. Fig. 5 shows the wind profile for Botswana (Meteoblue, n.d.). In operating electrical energy system, it is essential to ensure that the demand and supply are balanced and equal. It is difficult to store electricity, though technologies have contributed to it and are steadily improving (Kempener et al., 2013).

According to Africa progress panel, the region spends billions of dollars on utility losses and subsidies thereby hampering the power sector development. This reflects on the investors who perceive the sector as ‘High Risk’ as most utility companies cannot recover the costs without these subsidies, thus making it unattractive. Therefore, it attracts limited the investment to energy commodities and into in the sector. The key to reducing this gap is to reform energy utilities and their regulations improving operational efficiency thereby enhancing regional cooperation and thus attracting investments from private players (Africa Progress Panel, 2015). Regulatory framework poses a more significant challenge in terms that the organizations tend to be conservative in calculating the benefits in what they can gather as cash benefits to the shareholders. It is considered that the operative losses are passed onto the customer, and as a result, any drop in losses would impact the utility shareholder. Therefore regulators are required to place such policies and regulations in place that could benefit both the utility and consumer.

Challenge in the form human resources element adds to the electricity crises. Botswana, as a nation has a mostly unskilled workforce and the unemployment rate is roughly about 40%. This is primarily due to the non-availability of necessary skills sets. This is further aggravated by the fact that finding sufficiently skilled workforce and training them for the job and retaining them can be a challenge and this multiplies manifold when the human resource has to be multiplied to scale up the program. Aligning them with DER’s remains a test (Bhattacharyya and Palit, 2016).

Though energy theft in developed countries like UK and US, is not a problem, in a developing country like Botswana, it poses a far more significant challenge. The reason being people have little understanding or no insight of the grid, and with higher poverty ratio, power theft is quite rampant. Mike (Mooiman, 2016) in his blog mentions how it has been a challenge into one of the implemented PV project in Pakhalane, Gaborone in Botswana. The single biggest problem is vandalism and panel theft for copper. As reported, as many as six panels were stolen from the facility and large amounts of grounding cables were stolen for their copper value, thus making the facility unusable. Thus it is evident that

the panels and cables are of inherent value and their theft adds to glitches in providing electricity. The socio-economic condition of the region is one contributing factor to the theft.

3.1. Non-technical challenges

With extensive renewable shares in the smart systems, it changes the very nature of how electricity grid operates. However, besides technical challenges mentioned earlier, some critical non-technical challenges need to be addressed.

3.2. Data access and ownership

With extensive smart grid networks, the amount of data involved is huge. Data that is personal and of high value. The data is used both by the consumer and the distributor. The consumer will be interested in what are his needs and will help him manage his consumption, while at the same time, the distributor will be looking towards the consumer data for efficiently managing the system, and the manufacturer will be interested to know how the system is performing. The policymakers will also be interested in understanding the role of the renewable energy systems installed and how it is contributing to the country so that they can plan their energy plans for the country accordingly. Therefore it is critical to address on who owns the data and the level of access that needs to be given to each of the stakeholders. So there should be clear guidelines for all the stakeholders (Colorado Smart Grid Task Force, 2011; Kempener et al., 2013).

3.3. Data privacy

Another critical element related to data access and ownership in the smart grid is data privacy. Since it is closely related to internet resources, it is essential that the privacy of the consumer or prosumer, in this case, is respected. This raises a fundamental question as to how safe the data is to the prying eyes of others. Several studies have concluded that the consumer privacy must be protected for the smart grid to achieve social acceptance (Kempener et al., 2013).

3.4. Cybersecurity

As Botswana gears up for investment in the Smart Grid technology hugely to meet its growing energy demand in the country, with the transition from analogous to digital electricity, there are numerous infrastructure challenges associated with it. One of the key challenges is in communication. With communication comes security, data management, etc. where there is a huge gap, as digital networks are more prone to cyber-attacks from software hackers. Thus security becomes the primary issue that needs to be addressed. Security concerns on the invasion of privacy and personal consumption data arises with the new digital electricity infrastructure. Traffic Management in smart grids—virtual power plants will rely on large-scale simulation and multi-route planning. This will create a massive influx of software demand and will aid in developing software functionality in virtualization. Virtualization of the power grid will create dependability problems compromising security. Thus integrity forms the core essentials of the VPP grid. Botswana at present has no specific cybersecurity policies or mandates. Sporadic cybersecurity attacks like the Stuxnet, Shamoon across the globe in various countries, have indicated that these attacks can cause significant damage and pose a risk to National Critical Infrastructure. Thus it is essential that there be no gaps in security planning as part of designing the smart grids, which otherwise can potentially leave gaping holes in the Botswana’s power sector stability. “With the evolution of cyber

threats/attacks over time, the motivation of the attackers also evolved significantly driven by financial gain (Kumar et al., 2013). It has transformed from organized crime in well-established marketplaces for trading in malware and stolen credit card data to attacks that are designed to create mayhem and cripple the National Critical Infrastructure (NCI) (Kumar et al., 2013).

The envisioned grid is a potential target for the malicious hackers, and well-motivated adversaries as studies and experiences in the IT and telecommunication system indicate. The grid can be subjected to physical attacks by a hacker or by using malicious software codes explicitly targeting the control systems or systems resources to accomplish one's tasks. One of the most excellent examples is DDOS attacks. These forms of attacks disrupting the grid can be highly motivating to a few and dangerous. It is likely to send out wrong signals in the energy market. Due to high grid efficiency and connectivity, the grid will enable personal information collection at ease and with it comes to a very crucial package "Customer Data". Any form of attack on this will be an invasion of the "consumer privacy". Threats on bills example manipulating with billing information of a particular or specific user can have a major disturbance on economic value unless monitored carefully. Since power grids play a major role in the National Defense systems, any form of attack on these grids can cause havoc. Any failure on the part of the stakeholders to eliminate these threats will hinder the modernization of the existing power industry. The existing well protected IT infrastructure, which encompasses contemporary security technologies such as Virtual Power Networks (VPN's), Intrusion Detection Systems (IDSs), public key infrastructure (PKI), anti-virus software, firewalls, cannot be very effective by direct deployment on the smart grid unless some critical changes are effected into the system due to inherent differences prevalent in them. "The North American Equipment Council (NREC) reported the effects of a slammer worm on the power utilities used over in North America. In a quoted example they claim: The worm migrated through a VPN connection to a company's corporate network until it finally reached the critical Supervisory Control and Data Acquisition (SCADA) network. It infected a server on the control-center LAN that was running MS-SQL. The worm traffic blocked SCADA traffic" (Liu et al., 2012).

With the advent of smart grids and their ability to generate huge data on consumer, about their usage and patterns in usage of electricity and other personally identifiable information PII security is paramount. This is, in fact, another area that the security should be focused on. This data in any wrong hands can be misused wreaking havoc. This information can be used against the very own consumer as his usage "can reveal whether a person is at home or away, or what kind of devices being used". This is in addition to the security attention that needs to be provided to the critical infrastructure (Kumar et al., 2013).

In addition to going smart, one other way of overcoming the regional challenges is through regional power pools. These power-pools allow countries to aggregate its energy resources and extend grids across national borders to capitalize on regional diversity in resources and demand (Avila et al., 2017). Currently, there are four regional power pools in operation. However, only 7% of electricity is traded across international borders, mostly through the South African Power Pool (SAPP). Formulating more efficient use of these power pools in the region could potentially save over \$50 billion in capital investments in the power sector (Castellano et al., 2015; Avila et al., 2017).

3.5. The role of renewable energy and fully distributed generation

The change in thoughts with a desire to fight climate change and increase energy production through clean energy and energy security is the critical driver for the success of renewable energy

power generation. However, increasing renewable energy in a system that is inflexible and complex is a significant challenge for DER operators. Integration of distributed renewable energy systems into the mainstream grid is still researched due to its fluctuating nature. This is further weakened due to the market signals plagued by two components; first renewable energy is prioritized under fixed feed-in tariffs and exempted from market prices, second generators in DER's are small operators and often not equipped with technology and characteristics for system management. This opens up a wide range of opportunities in developing community-based grids or virtual power plants, where an aggregator or a TSO operator controls the DER environment; Most renewable energy sources like PV generates power differently than the traditional conventional way in the past. Power electronics and advanced IT systems are used to integrate it with the grids. Since in renewable energy power generation is scalable due to its flexibility of generating power in few kilowatts to megawatts, from rooftop residences to commercial generation, from biowaste to PV, it can be used in communities and villages with or without electricity to enhance sustainable living and develop the community as a whole (Alonso et al., 2012; Phuangpornpitak and Tia, 2013; Alagoz et al., 2012; Christine et al., n.d.).

4. Case studies

In an endeavor to promote the use of solar power, the first project in terms of implementing PV projects was carried out by Government of Botswana in 1992 in Manyana. This pilot project was carried out under Energy Affairs Division. The installations included 42 residential PV lighting systems, one photovoltaic AC lighting system for the clinic, one photovoltaic vaccine refrigerator or the clinic, six solar water heaters and seven photovoltaic streetlights. After two years of successful monitoring and implementation, the findings were impressive and revealed that the technologies were socially accepted and there has been an increase in economic activities as well as improvement in the medical care capabilities in the village (Matshameko, 2004). In a growing concern of providing electricity access to all its citizens, in alignment with its vision 2016 and to address the issue of energy provisions, Government of Botswana in a joint collaboration with Japanese International Cooperation Agency (JICA), put into operation a pilot project on trial basis in 3 villages Kudumatse, Lorolwana and Motlhabaneng with intention to provide power through PV arrays and with a view to gather data for rural electrification through the project aimed at meeting electricity needs for rural community. The installed capacity ranged from 50 to 250 Wp. The project started in 2002 and ended in 2006. The BPC monitored the implementation and were technically the 'Owners' of the system, charging a monthly rental fee for the household's service by the system. Monthly payments ranged between Botswana Pula 40 to 120 for a 50–250Wp system. A total of 114 systems were installed, and 42 were repossessed due to nonpayment of dues (Ketlogetswe and Mothudi, 2009; IEA, n.d.).

Apart from the above systems aimed as a pilot study, Botswana has three grid-connected systems. A 1300 kW solar power form in Pakhalane as a part of Japanese aid, near Gaborone, a 20 kW system installed in Mokolodi village funded by the European Union and a 34 kW system owned by a private operator. In addition to the above, there are a number of small-scale installations that are grid connected. If these small individual resources are pooled together to form a smart mini-grid, it will enhance the livelihood of the small communities that house them both economically and enhancing sustainable energy. The systems are performing well-providing electricity to the installations. This emphasizes that there be enough and more scope for development of small-scale DER's that can help mitigate the energy shortage without adding to climate.

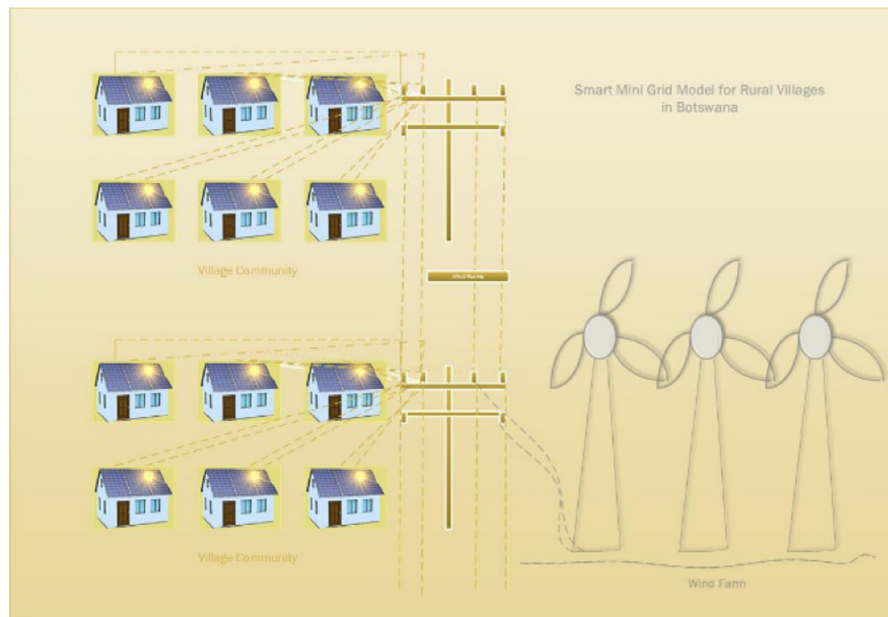


Fig. 6. Smart mini grid model.

4.1. Lessons from the project

As indicated in the case studies, the project selection was for different communities of different socio-economic backgrounds through alternative means for providing electricity to the community.

4.2. Development of community-based grid in villages

Rural villages in Botswana remains poorly electrified. Given the scope and success of the PV systems, there is huge scope for forming a *SMART Mini Grid*-based electrification. These Smart Mini Grids could include smart futures after practical considerations. Since most of the areas receive ample sunlight, Solar PV models can be chosen in conjunction with biomass. The *Kgotla*² in existence with their leader as a representative could be responsible for managing and operating the system, including the collection of revenues and resolving any disputes or addressing the grievances relating to either the system or the model. The successful system model design, like the one used in villages in Odisha in Indian State, could be used with some additional smart features like (Bhattacharyya and Palit, 2016). A small model that could be adopted, is shown in Fig. 6.

- Smart system design for segregating loads
- Feeder segregation for residential and industrial load
- Allowance for demand growth
- Grid-tied inverter can be used to ensure integration to the central grid.

5. Discussion

Smart Grid VPP model is an emerging technology in Sub-Saharan Africa as compared to other nations across the globe. There are inherent challenges in the smart grids. These challenges need to be taken into account when implementing and deploying smart technologies in Botswana. Successful PV models indicate that there

is a huge scope for the expansion in the region of Botswana. It is essential that the renewable electricity generation components be encouraged and implemented to meet the demand of achieving the reduction in carbon print while doubling the renewable energy share in the market. While this transition is feasible and achievable, the grids need to be upgraded with new innovative technological solutions should be accommodated. Smart grids essentially incorporate many components just as in traditional systems and absorb them (see Fig. 7).

Although the challenges above are critical, steps in the right direction will help speed up the adaptation of smart technologies. One of the foremost steps is to ensure that steps should be taken by the policy-makers and regulators in addition to restructuring the economic incentives and align risk. By encouraging private–public partnership, building the right environment in the economy for the private sector investment and analyzing these solutions in smaller environments, i.e., in villages, the entire industry will learn what it takes to implement smart technologies successfully and will result in developing an industry that is set to boom in the coming periods. Optimally spread framework across the chain guarding and minimizing the investors from risk needs to be implemented. Risks associated with technology and delivery are significant in VPP's smart grids. The identified risks need to be shared in the chain to have an efficient delivery chain. A clear mechanism should exist on how much risk each associated member can take. The rate of return should be determined based generated output. Mechanisms should be in place for rewards and penalty to monitor the performance of the utilities. It is clear that the decisions will be driven by the society to address the challenge of the transition to digital infrastructure driven by utility-centric investment that will determine scopes of the Smart Grid. This would help in the enhanced adoption of smart technologies by the society and the common man. It is essential that the VPP Smart grid concentrates on building greater efficiency into the energy system to reduce losses, peak load demand, and decreasing generation as well as energy consumption. This would also aid in reduced greenhouse gases emission (North American Electric Reliability Council, 2003).

Since Smart Grid–Virtual Power Plant has got the potential to change the business model of electricity generation, it will dictate

² Village Committee.

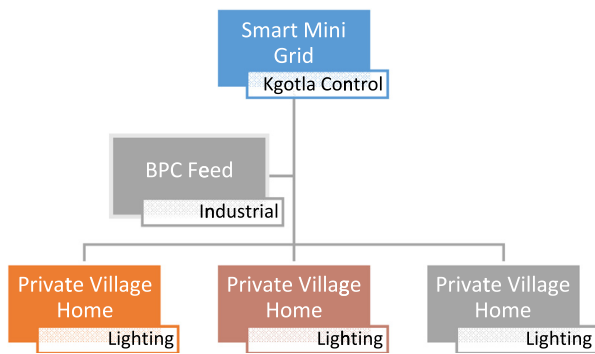


Fig. 7. Smart mini grid model for rural villagers in Botswana.

on where, when and how energy is produced. In this scenario, every household and business will be a prosumer as well as a consumer since they will act as small micro generators. With the rise in VPP technologies, an economic situation will evolve in the right direction, as the traditional energy cost and distributed generation are inversely proportional. “As the cost of traditional energy sources continues to raise the cost of distributed generation technologies will fall”. This will benefit both the consumer and the prosumer over a period. The energy producer, in this case, village community will play a vital role in ensuring that the systems are connected the grid and the prosumer is protected with a sustainable income. The assurance on the sustainable income will be from selling the excess produced electricity back to the grid through the village connected VPP. This will also enhance and strengthen the bond among the community since their livelihood will depend on the energy from community grid.

Based on the lessons from the action research, it is essential to formulate a proper model as one model does not fit everyone. Local contexts regarding climate, socio-economic conditions, resources potential both human capital and natural resources, institutional and political conditions must be taken into account before creating a successful model in the region. Botswana has a cattle population of over 2 million. This indicates that there enough and more scope for development of biomass model in the villages. This could be tried out on a trial basis. Due to climate profile of Botswana, the successful model adopted by other nations in biomass and PV could be taken up to assist the Socio-Economic conditions of the people in the rural areas. Success in the PV model where BPC has installed, commissioned and monitored small off-grid individual generators with a minimum rent, the model could be used in the smart mini grid model. With sufficient awareness, the excess power generated when fed back to the grid could enhance the livelihood of the small individual village houses with either rooftop or PV array installed. With adaptation of smart mini grid model.

6. Conclusion

The model described in this paper could provide a possible solution to increase energy production, while enhancing the sustainability of the rural villagers. It could also provide a possible solution to increase and address core areas in smart technologies and competence for higher smart grid accessibility. Since the Sub-Saharan Climate profile is different regarding accessibility and distances, the demands are closely related to generation, reducing transmission and distribution losses while creating cheaper forms of energy and also contributing to reducing the carbon footprint. It is essential that lessons from other smart grid models be addressed when deploying new models as a solution.

References

- Abdolrasol, Maher G.M., Mohamed, Azah, Hannan, M.A., 2017. Virtual power plant and microgrids controller for energy management based on optimization techniques. *J. Electr. Syst.* 13 (2), 285–294 Retrieved from http://journal.esrgroups.org/jes/papers/13_2_6.pdf.
- Africa Progress Panel. 2015. Power, people, planet: Seizing Africa's energy and climate opportunities: Africa progress report. Africa Progress Panel. Geneva: Africa Progress Panel. (Retrieved 05.17.17), from http://www.africaprogresspanel.org/wp-content/uploads/2015/06/APP_REPORT_2015_FINAL_low1.pdf.
- Alagoz, B.B., Kaygusuz, A., Karabiber, A., 2012. A user-mode distributed energy management architecture for smart grid applications. *Energy* 44 (1), 167–177.
- Alonso, M., Amaris, H., Alvarez-Ortega, C., 2012. Integration of renewable energy sources in smart grids by means of evolutionary optimization algorithms. *Expert Syst. Appl.* 39 (5), 5513–5522.
- Asmus, P., (2017,01 07). Honey, I Shrunk The Grids: The Emergence Of Nanogrids - NWPPA. doi:Retrieved from <https://www.nwppa.org/wp-content/uploads/02-NWPPA-Nanogrids-Asmus.pdf>.
- Avila, Nkiruka, Carvallo, Juan Pablo, Shaw, Brittany, Kammen, Daniel M., 2017. Part 1: Generating Energy for Sustainable and Equitable Development. (O. Research, Ed.). In: Oxfam Research Backgrounder Series, vol. 1, pp. 1–79 (1), Retrieved from <https://www.oxfamamerica.org/static/media/files/oxfam-RAEL-energySSA-pt1.pdf>.
- Bahrman, M., Johnson, B., 2007. The ABCs of HVDC transmission technologies. *IEEE Power Energy Mag.* 3/4, 32–44.
- Bazilian, Morgan, Nussbaumer, Patrick, Haites, Erik, Levi, Michael, Howells, Mark, Yumkella, Kandeh K., 2010a. Understanding the scale of investment for universal energy access. (J. Rozhon, Ed.). *Geopolitics of Energy* 31 (10–11), 24.
- Bazilian, Morgan, Sagar, A., Detchon, R., Yumkella, K., 2010b. More heat and light. *Energy Policy* 38 (10), 5409–5412.
- Bazilian, Morgan, Welscha, Manuel, Divanb, Deepak, Elzingac, David, Strbacd, Goran, Lawrence, , Howells, Mark, 2013. Energy futures lab. In: Smart and Just Grids: Opportunities for Sub-Saharan Africa. Imperial College, Imperial College of Science, Technology, and Medicine, London, . <http://dx.doi.org/10.1016/j.rser.2012.11.004>.
- Bello, Mobolaji, Smit, Riaan, Carter-Brown, Clinton, Davidson, Innocent E., 2013. Power planning for renewable energy grid integration - Case Study of South Africa. In: 2013 IEEE Power & Energy Society General Meeting. IEEE (Ed.), pp. 1–5. <http://dx.doi.org/10.1109/PESMG.2013.6672904>.
- Bhattacharyya, Subhas C., Palit, Debajit, 2016. Mini Grid based off-grid electrification to enhance electricity access in development countries - What policies may be required. (S. Direct, Ed.). *Energy Policy* 94, 166–178. <http://dx.doi.org/10.1016/j.enpol.2016.04.010>.
- Biro, Fatih, 2010. World energy outlook 2010. Paris. In: OECD/International Energy Agency. International Energy Agency, Paris.
- Botswana Power Corporation. 2015. Annual Report - BPC 2015. Gaborone, Botswana: Botswana Power Corporation.
- Buhler, Raffael, 2010. Integration of Renewable Energy Sources using Microgrids, Virtual Power Plant and Energy Hub. Swiss Federal Institute of Technology (ETH) Zurich, EEH Power Systems Laboratory, Zurich, Switzerland: Eidgenossische Technische Hochschule, Retrieved from <https://www.ethz.ch/content/dam/ethz/special-interest/itet/institute-eeh/power-s>.
- Castellano, A., Kendall, A., Nikomarov, M., Swemmer, T., 2015. Brighter Africa: The growth potential of the sub-Saharan electricity sector. McKinsey Report. McKinsey & Company. (Retrieved 16.05.17), from <http://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/powering-africa>.
- Christine, B., Gert, B., Nele, F., (n.d.). Smart Pricing to Reduce Network Investment in Smart Distribution Grids - Experience in Germany. <http://doi.org/10.1016/B978-0-12-386452-9.00013-9>.
- Clark, G.W., 2009. What is the Smart Grid? In: Clark, G.W. (Ed.), In the Smart Grid: Enabling Energy Efficiency and Demand Response. The Fairmont Press, Inc, Lilburn, GA, USA.
- Clement, Kevin, (n.d.). Smart Grid Technology. (Retrieved 05.12.17), from <https://smartgridtech.wordpress.com/smart-grid/>.
- Colorado Smart Grid Task Force, 2011. Deploying Smart Grid in Colorado: Recommendations and Options, Final Report. Meridian Institute, Washington DC, USA, (Retrieved 05.20.17) from www.merid.org/en/Content/Projects/Colorado_Smart_Grid_Task_Force.aspx?view=docs.
- Davis, S.C., 1999. Transportation Energy Databook. In: Davis, S.C. (Ed.), Center for Transportation Analysis (19th Edition ed.). Oak Ridge National Laboratory US Department of Energy.
- Deichmann, Uwe, Meisner, Craig, Murray, Siobhan, Wheeler, David, 2011. The economics of renewable energy expansion in rural Sub-Saharan Africa. (E. Science Direct, Ed.). *Energy Policy* 39, 215–227. <http://dx.doi.org/10.1016/j.enpol.2010.09.034>.
- DHS. 2009. DHS (Demographic and Health Surveys). Reported by Measure DHS STAT compiler. Retrieved from <http://www.statcompiler.com>.

- Diaz-Cayeros, A., Estévez, F., Magaloni, B., 2013. Strategies of Vote Buying: Poverty, Democracy and Social Transfers in Mexico.
- Fangxing Fran, Li, Qiao, Wei, Sun, Hongbin, Wan, Hui, Wang, Jianhui, Xia, Yan, Xu, Zhao, Zhang, Pei, 2010. Smart transmission grid: Vision and framework. (IEEE, Ed.). IEEE Trans. Smart Grid 1 (2), 168–177. doi:1109/TSG.2010.2053726.
- Foster, V., Cecilia, B.-G., 2010. Africa'S Infrastructure: A Time for Transformation. World Bank Publications, Washington DC.
- Franke, Markus, Rolli, Daniel, Kamper, Andreas, Dietrich, Antje, Geyer-Schulz, Andreas, Lockemann, Peter, Schmeck, Hartmut, Weinhardt, Christof, 2012. Impacts of Distributed Generation from Virtual Power Plants. 12(76131).
- Herbst, J., 2002. States and Power in Africa. Princeton University Press, Princeton, New Jersey.
- Hoeven, M.V., 2014. Africa Energy Outlook. International Energy Agency. (Retrieved 6.16.17), from https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf.
- IEA, 2012. Energy Technology Perspectives 2012. IEA.
- IEA, 2014a. Africa Energy Outlook: A Focus on Energy Prospects in Sub-Saharan Africa. International Energy Agency, Paris.
- IEA, 2014b. World Energy Outlook. International Energy Agency, Paris.
- IEA, (n.d.). PV System Pilot Projects, <http://www.ripco.co.bw/homepage.aspx> (IEA, Editor, & IEA) (Retrieved 05.19.17), from International Energy Agency: <https://www.iea.org/policiesandmeasures/pams/botswana/name-24581-en.php>.
- Kanagawa, Makoto, Nakata, Toshihiko, 2008. Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries. In: Energy Policy, Vol. 36. (Elsevier, Ed.), pp. 2016–2029.
- Kempener, Ruud, Komor, Paul, Hoke, Anderson, 2013. Smart Grids and Renewables: A Guide for Effective Deployment. International Renewable Energy Agency (IRENA), IRENA. Abu Dhabi, UAE: IRENA. Retrieved 05 19, 2017, from www.irena.org.
- Keteloetswe, C., Mothudi, T.H., 2009. Solar home systems in Botswana—Opportunities and constraints. Renewable Sustainable Energy Rev. 13 (1), 1675–1678. <http://dx.doi.org/10.1016/j.rser.2008.08.007>.
- Knoepfel, I., 1996. A framework for environmental impact assessment of long-distance energy transport systems. Int. J. Energy 21 (7/8), 693–702.
- Kroth, V.L.V., 2014. A better life for all? Democratization and electrification in post-apartheid South Africa. London School of Economics Working Paper.
- Kumagai, J., (2012, 02 24). Virtual Power Plants, Real Power, 5 Kw here and 100 Kw there it all adds up.
- Kumar, Anand, Pandey, Krishnan, Punia, Devendra Kumar, 2013. Facing the Reality of Cyber Threats in the Power Sector. (Wipro, Ed.) White Paper.
- Lake, D.A, Baum, B.M., 2001. The invisible hand of democracy political control and the provision of public services. Comp. Polit. Stud. 36 (4), 587–621.
- Liu, Jing, Xiao, Yang, Li, Shuhui, Liang, Wei, Philip Chen, C.L., 2012. Cyber security and privacy issues in smart grids. IEEE Commun. Surv. Tutor. 14, (4, Fourth Quarter).
- Ma, Zheng, Lundgaard, Morten, Jørgensen, Bo Nørregaard, 2016. Triple-layer smart grid business model - A comparison between Sub-Saharan Africa and Denmark. In: IEEE (Ed.), Innovative Smart Grid Technologies - Asia (ISGT-Asia). IEEE, Melbourne, Australia, pp. 352–374 doi:978-1-5090-4303-3.
- Matshameko, T.C., (April 15–16, 2004). Public Private Solar Energy Service Delivery in Rural Areas in Botswana. Ministry of Minerals, Energy and Water Affairs, Energy Affairs Division (EAD). Windhoek, Namibia.
- Meteoblue, (n.d.). Weather and Climate, Climate Botswana. (Meteoblue) Retrieved 05 20, 2017, from Meteoblue Climate: https://www.meteoblue.com/en/weather/forecast/modelclimate/botswana_south-africa_1016666.
- Mooiman, M., (2016, 2 14). Grid-Connected Solar Energy Projects in Botswana. (Retrieved 05.19.17), from botswanaenergy.blogspot.com: http://botswanaenergy.blogspot.com/2016/02/grid-connected-solar-photovoltaic_14.html.
- North American Electric Reliability Council. (2003, Jun). SQL Slammer worm lessons learned for consideration by the electricity sector. Retrieved from <http://www.esisac.com/publicdocs/SQLSlammer2003.pdf>.
- Oliver, Jeannie, Sovacool, Benjamin, 2017. The energy trilemma and the smart grid: Implications beyond the united states. Asia Pac. Policy Stud. 4 (1), 70–84. <http://dx.doi.org/10.1002/app5.95>.
- Oudalov, A., Reza, M., (September 16–19; 2007). Externality implication on bulk energy transport. 127th US Association for Energy Economics Conference. Houston, USA.
- Palit, Debajit, Chaurey, Akanksha, 2011. Off-grid rural electrification experiences from South Asia: status and best practices. (S. Directo, Ed.). Energy Sustain. Dev. 15 (3), 266–276. <http://dx.doi.org/10.1016/j.esd.2011.07.004>.
- Paul, Cook, 2011. Infrastructure, rural electrification, and development. (Elsevier, Ed.). Energy Sustainable Dev. 15 (3), 304–313. <http://dx.doi.org/10.1016/j.esd.2011.07.008>.
- Phuangpornpitak, N., Tia, S., 2013. Opportunities and challenges of integrating renewable energy in smart grid system. In: 10th Eco-Energy and Materials Science and Engineering Symposium. In: Energy Procedia, vol. 13, Elsevier (Ed.), pp. 282–290.
- Pillota, Benjamin, Muselli, Marc, Poggi, Philippe, Dias, João Batista, 2017. On the impact of the global energy policy framework on the development and sustainability of renewable power systems in Sub-Saharan Africa: the case of solar PV. arXiv preprint arXiv:1704.01480.
- Rodríguez-Molina, Jesús, Martínez-Núñez, Margarita, Martínez, José-Fernán, Pérez-Aguar, Waldo, 2014. Business models in the smart grid: Challenges, opportunities, and proposals for prosumer profitability. In: Energies Open Access. (Elsevier, Ed.), pp. 6142–6171. <http://dx.doi.org/10.3390/en7096142>.
- Sampath, Kumar V., Prasad, Jagdish, Samikannu, Ravi, 2017. Challenges, Opportunities and profitability in virtual power plant business models in sub saharan Africa - Botswana. (I. Ozturk, Ed.). Int. J. Energy Econ. Policy 7 (3), 1–11.
- Sebitosi, A.B., Okou, R., 2010. Re-thinking the power transmission model for sub-Saharan Africa. Energy Policy 38, 1448–1454.
- Siverson, R., Morrow, J.D., Bueno de Mesquita, B., Smith, A., 2003. The Logic of Political Survival. (M. Press, Ed.).
- Solar GIS. (n.d.). (Retrieved 2.28.17), from <https://solargis.info>.
- Trotter, Philipp A., 2016. Rural electrification, electrification inequality, and democratic institutions in sub-Saharan Africa. Energy Sustainable Dev. 34, 111–129.
- UN. 2015. Transforming our world: The 2030 Agenda for Sustainable Development. United Nations. (Retrieved 05.16.17), from sustainabledevelopment.un.org.
- UNEP, ILO, IOE, and ITUC. 2008. Green Jobs: Towards decent work in a sustainable, low-carbon world. United Nations Environment Programme. Policy Options for Africa. United Nations. United Nations. Retrieved from http://www.unep.org/labour_environment/PDFs/Greenjobs/UNEP-Green-Jobs-Report.pdf.
- USAID. 2016. USAID Power Africa. (Retrieved 05.17.17), from USAID : <https://www.usaid.gov/powerafrica/botswana>.
- VPP. 2015. Virtual Power Plants. Retrieved from <http://www.navigantresearch.com/research/virtual-power-plants>.
- WHO, Global Health Observatory. (n.d.). Urban Population Growth. (Retrieved 05.12.17) from http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/.
- Wu, G.C., Deshmukh, R., Ndhlukulac, K., Radojicic, T., Reilly, J., 2015. Renewable Energy Zones for the Africa Clean Energy Corridor. International Renewable Energy Agency and Lawrence Berkeley National Laboratory, LBNL. International Renewable Energy Agency and Lawrence Berkeley National Laboratory.