

Smart and Just Grids: Opportunities for sub-Saharan Africa

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Forward



Whilst there is a clear focus today on improving the energy security and sustainability of established economies in Europe, Japan and North America, for example, as well as rapidly growing economies such as China, we must not forget that energy security means something very different to the many millions of people who have no access to electricity of any kind.

This paper “Smart and Just Grids: opportunities for sub-Saharan Africa” tackles this very important issue, setting out the current challenges and highlighting the role that the rapidly evolving technological and commercial concept of smart grids could play in ensuring a reliable and secure electricity supply for the region.

The paper is essential reading for anyone interested in the provision of energy in a sustainable, secure and affordable way in developing economies, and in the role that smart grids can play in transforming energy supply infrastructures and associated business models.

Energy is a strategic research priority at Imperial College London, and we are committed to delivering solutions to the global energy challenge. After reading this paper, I hope you are too.

A handwritten signature in black ink, which appears to read "N. Brandon". The signature is written in a cursive style and is underlined.

Professor Nigel Brandon FEng
Director, Energy Futures Lab
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Preamble

In 2009, an estimated 585 million people had no access to electricity in sub-Saharan Africa. Unlike many other regions of the world, under current assumptions, that figure is expected to rise significantly by 2030 to about 652 million – an unsustainable and unacceptable situation. National governments and regional organisations have identified the urgent need for accelerated electrification rates. Responding to this need will require innovative and effective energy policies. The way future power systems are planned, designed, constructed, financed and operated will have a significant impact on how effectively these aspirations are delivered.

Some of the well-known and emerging concepts, systems and technologies of Smart Grids may offer an important contribution to universal access to electricity in sub-Saharan Africa. We argue that these Smart Grid advances may enable sub-Saharan African countries to leapfrog elements of traditional power systems in terms of both technology and regulation. This could accelerate national and regional electrification timeframes, improving service delivery, minimizing costs and reducing environmental impact.

We introduce the notion of *Just* Grids to reflect the need for power systems to contribute towards equitable and inclusive global, economic and social development. While Smart Grids may provide an efficient mechanism to address the massive electricity infrastructure building requirements, *Just* Grids will help guarantee access to modern energy services without marginalizing the poor. This paper presents the concept of Smart and Just Grids, and considers specific priorities that could usefully be implemented in sub-Saharan Africa in the short-term. It reviews the literature, provides a foundation for policy development, and suggests areas for further, more detailed research.

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1. Introduction

According to the International Energy Agency (IEA) reference scenario, Africa's final electricity consumption is expected to double between 2007 and 2030 from 505 to 1012 TWh (IEA 2009). Over the same time period, the United Nations (UN) Secretary-General's Advisory Group on Energy and Climate Change (AGECC) has proposed that the UN System and Member States commit to ensuring universal access to reliable, affordable and sustainable modern energy services by 2030 (AGECC 2010). To meet this goal, massive electricity infrastructure² development will be required in the short- and medium-term.

The IEA (2010) estimates that achieving universal access to electricity by 2030 will require additional power-sector investment of USD 33 billion per annum on average, much of which is needed in sub-Saharan Africa. Efficiency improvements, demand management, optimal generation planning, improved grid operation and increased electricity trade across sub-Saharan African countries will be essential for minimizing the volume of investments needed (UN-Energy Africa 2008). We propose that specific elements of current and emerging Smart Grid³ concepts, systems and technologies may make an important contribution to improving equitable and just access to electricity services in sub-Saharan Africa (Bazilian, Sagar, et al. 2010).

This paper first briefly describes the electricity sector in sub-Saharan Africa, including regional initiatives, power pools and regulatory authorities (Section 1). Section 2 reviews current Smart Grid concepts, technologies and related costs and benefits. Section 3 places the Smart Grids concept in the context of sub-Saharan Africa, shifting the focus towards the facilitation of just access. It illustrates potential opportunities for leapfrogging elements of traditional power systems, the role of energy planning, and effects on regulation and market design. Finally, Section 4 offers thoughts on how to apply specific concepts in the short-term, and suggests areas for international cooperation to complement ongoing and planned regional and national initiatives in sub-Saharan Africa. This paper represents only an initial foundation for policy design and further, more detailed research.

1.1 ELECTRICITY IN SUB-SAHARAN AFRICA

The energy sector in sub-Saharan Africa is characterised by significant challenges including: low energy access rates, electricity costs as high as USD 0.50/kWh, insufficient generation capacity to meet rapidly rising demand, and poor reliability of supply (WB 2008). The estimated economic value of power outages in Africa amounts to as much as 2% of GDP, and 6-16% in lost turnover for enterprises (WB 2009).

In 2009, around 585 million people in sub-Saharan Africa (about 70% of the population) had no access to electricity (IEA 2010). This figure is expected to rise significantly to about 652 million people by 2030. Urban centres in sub-Saharan Africa are covered by varying electricity quality levels from national and regional

² We use the term *electricity infrastructure* or *power systems* to encompass the entirety of the system, from generation through transmission and distribution to customer services and associated operations.

³ It remains the case that modern power system planning and operational tools and systems currently employed in the OECD also have much to offer developing countries.

grids, but rural coverage is particularly uneven and inadequate (Parshall et al. 2009) - 80% of those without access to electricity live in rural areas (IEA 2010).

In 2007, sub-Saharan Africa produced 390 TWh of electricity, of which South Africa alone produced almost 70% (AfDB, AU, and UNECA 2010)⁴. For a sense of scale, with 68 GW, the entire generation capacity of sub-Saharan Africa is no more than that of Spain⁵. In addition, sub-Saharan Africa's average generation capacity was only about 110 MW per million inhabitants in 2007, ranging from less than 15 MW per million inhabitants in Guinea-Bissau and Togo, to 880 in South Africa, and up to 1,110 in the Seychelles (EIA 2010). By comparison, the generation capacity in the European Union is about 1,650 MW per million inhabitants, and in the U.S. it is 3,320.

Africa's energy resources are characterised by oil and gas reserves in North and West Africa, hydroelectric potential in Central and Eastern Africa, and coal in Southern Africa. Hydropower in sub-Saharan Africa has an enormous exploitable potential (WEC 2005): it currently accounts for 45% of sub-Saharan Africa's current electricity power generation (AfDB 2008)⁶, which represents only a fraction of the commercially exploitable potential. In addition, sub-Saharan Africa has abundant solar potential (Huld et al. 2005), and biomass is used extensively for household use, with prospects for increased commercial exploitation and electricity production (UNIDO 2009).

Expanding access to national electricity grids often constitutes the cheapest option for providing services. However, decentralized power, often based on renewable energy sources, is likely to be an important component of any significant expansion in electricity access, especially for rural and remote areas (Deichmann et al. 2010). Both system types can benefit from aspects of Smart Grid technologies⁷.

1.2 REGIONAL AND NATIONAL INITIATIVES

The significant need for accelerated electrification rates has been identified by regional economic communities and national governments⁸. In 2007, the Africa-EU Energy Partnership was launched (AUC and EC 2008; AUC and EC 2007) to support regional energy strategies, policies and targets. These regional

⁴ Refer to Niez (2010) for more details on South Africa's electricity sector and policies.

⁵ Without South Africa, this capacity goes down to 28 GW, 25% of which is currently not available for generation due to, amongst others, aging plants and lack of maintenance (Eberhard et al. 2008).

⁶ Selected electricity supply information: West African (ECOWAS) region: 64% thermal power, 31% hydro power (GTZ 2009a). East African (EAC) region: 65% hydro power, 28% thermal power (GTZ 2009b). South Africa: 94% thermal power (AfDB, AU, and UNECA 2010).

⁷ We do not make a judgement on the issue of one type as superior to another, but rather consider how modern power system tools can benefit both as well as, in some cases, facilitate the connection of one into the other.

⁸ Such as: The Forum of Energy Ministers of Africa's (FEMA) Position Paper on Energy and the MDGs (WHO and UNDP 2009); The Southern African Development Community's (SADC) Protocol on Energy (L. Kritzinger-van Niekerk and E. Pinto Moreira 2002) and its Regional Indicative Strategic Development Plan (RISDP) (SADC 2003); The Economic Community Of West African States' (ECOWAS) Energy Protocol (ECOWAS 2003) and its White Paper for a Regional Policy (ECOWAS 2006); The Common Market for Eastern and Southern Africa's (COMESA) Energy Programme (COMESA 2009a); The East African Community's (EAC) Regional Strategy on Scaling-up Access to Modern Energy Services (EAC 2009) and its Power Master Plan Study (BKS Acres 2005); The Treaty Establishing the Economic Community of Central African States (ECCAS n.d.); The Economic and Monetary Community of Central Africa's (CEMAC) Energy Action plan with energy and electricity access goals (WHO and UNDP 2009).

ambitions are largely underpinned by national electrification policies, with more than 75% of sub-Saharan countries having defined targets for electricity access (WHO and UNDP 2009). The importance of regional and national electrification initiatives is clearly understood at the policy level. The priority is to translate this understanding into provision of electricity services ‘on the ground’.

1.3 REGIONAL POWER POOLS AND REGULATORY AUTHORITIES

In addition to regional economic communities and national governments, the main actors for implementing electrification plans are the regional power pools and utilities. Regional power pools were established under the auspices of Regional Economic Communities to create competitive markets and improve delivery services to customers (L. Musaba and P. Naidoo 2005). They comprise the Southern, West, East and Central African Power Pools (the SAPP, WAPP, EAPP and CAPP, respectively), all at different stages of development (IEA 2008a).

The SAPP provides the most advanced example of a regional power pool (Gnansounou et al. 2007)⁹ in sub-Saharan Africa: it was created in 1995 as a result of electricity trading in Southern Africa, which began in the early 1960s (Sebitosi and Okou 2009; SAPP 2008). The creation of the WAPP followed in 1999 (ECOWAS 1999; ECOWAS 2007), with the CAPP in 2003 (L. Musaba and P. Naidoo 2005) and the EAPP in 2006 (COMESA 2009b)¹⁰. After the regional power pools were created, regional electricity regulators were established by the Southern African Development Community (SADC), the Economic Community of West African States (ECOWAS) and the Common Market for Eastern and Southern Africa region (COMESA)¹¹.

Figure 1 provides an overview of the grid extensions foreseen by the regional power pools and utilities, with proposed projects showing the scale of opportunity for optimizing infrastructure design and delivery. It is clear that sub-Saharan Africa’s national grids are not well interconnected¹².

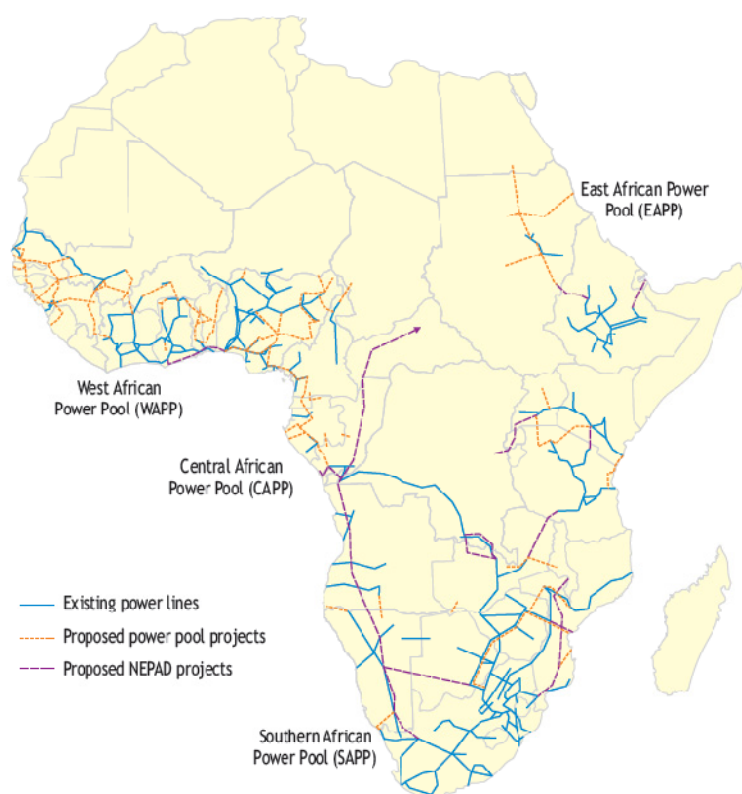
⁹ Each SAPP member country operates its own national utility (Bowen, Sparrow, and Yu 1999).

¹⁰ BKS Acres (2005) suggests the integration of the EAPP into the SAPP if the Zambia-Tanzania-Kenya interconnection is to be build.

¹¹ The Regional Electricity Regulators Association of Southern Africa (RERA) was established by SADC in 2002 to facilitate harmonisation and effective cooperation (RERA 2010). In 2008, ECOWAS established its Regional Electricity Regulation Authority (ERERA) to regulate electricity exchanges between states, and to support national regulatory entities (ERERA 2009). In 2009, energy regulators from COMESA countries formed the Regional Association of Energy Regulators for Eastern and Southern Africa (RAERESA) (COMESA 2009a).

¹² Typical transmission voltages used in Africa’s grids are mentioned in ESMAP (2007).

Figure 1: Power pools in sub-Saharan Africa [NEPAD 2008, as shown in (IEA 2008a)]¹³



2. A Smart Grid approach

Smart Grids combine a range of innovative tools and practices supported by novel business models and regulatory frameworks to help ensure a reliable, secure and efficient supply of electricity services. While there is strong consensus on this overall objective, the precise scope of the term Smart Grids is interpreted differently according to perspective and environment¹⁴ and it continues to evolve. A common functional and technical definition has yet to emerge (Brown, Technol, and Raleigh 2008). For our purposes, Smart Grids is a broad concept that covers the entire electricity supply chain and is characterised by the use of technologies to intelligently integrate the generation, transmission and consumption of electricity (MEF 2009). Thus, the elements of Smart Grids are part of a continuum of power sector tools and technologies. In this Section we draw from the literature to highlight specific aspects from the general Smart Grids discourse in industrialised countries, some of which we explore further in Section 3 for their short-term applicability to sub-Saharan Africa.

¹³ The difficulties in accessing the original source of this figure are representative for the overall time and effort required to access regional data and information on the status of electricity infrastructure in Africa.

¹⁴ For example, according to J. Antonoff, the U.S. focuses on technologies while the EU prioritises policies and strategies, assuming that technologies will follow (Asmus 2006).

2.1 DEFINING THE TERM

The Electric Power Research Institute (EPRI 2009) defines Smart Grid as, “a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers...and their devices”. Zibelman (2007) describes Smart Grids as an evolution of conventional grids in areas such as:

- Transitioning the grid from a mostly unidirectional radial distribution system to a multi-directional grid
- Converting from an electro-mechanical system to a primarily digital one
- Moving to an interactive grid that actively involves end-users (or at least improves data and flexibility of end-users)¹⁵

Much of the literature focuses on how Smart Grids can help establish a two-way flow of information between supplier and user to increase the efficiency of network operations (ETP SmartGrids 2006; DOE 2008; Larsen 2009; ROA 2009; Battaglini et al. 2009; Willrich 2009; Doran et al. 2010). The European Technology Platform (ETP) outlined the notion of Smart Grids (ETP SmartGrids 2010) in a similar manner through the following elements: optimizing grid operation, use and infrastructure; integrating large-scale intermittent generation; information and communication technology; active distribution networks; and new market places, users and energy efficiency. The U.S. Energy Independence and Security Act (2007) emphasised: full cyber-security, smart technologies and appliances¹⁶, timely consumer information and control, and standards for communication and interoperability¹⁷. It is thus clear that well-informed and robust regulation is a key foundation for all aspects of Smart Grids.

2.2 TECHNOLOGIES

While Smart Grids are composed of complex and integrated systems, they often build on proven advanced technologies¹⁸. Related technologies can generally be divided into those linked to physical power, data transport and control, and applications (Larsen 2009). The National Energy Technology Laboratory has identified and grouped many Smart Grid technology components (NETL 2007; NETL 2009)¹⁹:

¹⁵ Conventional grids usually provide detailed control at transmission level and good control at distribution level, but mostly do not go beyond that to control elements such as distributed energy sources or user appliances (Balijepalli, Khaparde, and Gupta 2009).

¹⁶ This refers to real-time, automated, interactive technologies that optimize the operation of appliances for metering, communications, and distribution automation, as well as peak-shaving technologies such as electric vehicles and thermal-storage air conditioning.

¹⁷ In a 2008 survey focusing on North America, respondents ranked the importance of Smart Grid features as follows: optimising distributed assets, incorporating distributed energy sources, integrating massively deployed sensors and smart meters, active consumer participation, self-healing technologies, advanced tools, smart appliances and devices and, least importantly, islanding ability - the ability of distributed generation to continue generating power even when power from a utility is absent (Brown, Technol, and Raleigh 2008).

¹⁸ Additionally, several promising technologies on the horizon may also form part of future grids, including: high temperature superconducting materials, advanced electric storage systems such as flow batteries or flywheels, and power electronics devices for AC-DC conversion (DOE 2003).

¹⁹ An alternative grouping of Smart Grid technology areas can be found in (IEA 2010).

- Integrated communications²⁰, including Broadband over Power Line (BPL), digital wireless communications or hybrid fibre coax;
- Sensing and measurement, including advanced protection systems, wireless, intelligent system sensors for condition information on grid assets and system status, and Advanced Metering Infrastructure (AMI);
- Advanced components, based on fundamental research and development, including Unified Power Flow Controllers (UPFC), Plug-in Hybrid Electric Vehicles and Direct Current micro-grids;
- Advanced control methods, to ensure high quality supply, including advanced Supervisory Control and Data Acquisition (SCADA) systems, load and short-term weather forecasting, and distributed intelligent control systems for Smart Grids to become self-healing;
- Improved interfaces and decision support, to reduce significant amounts of data to actionable information, including online transmission optimisation software, enhanced GIS mapping software and support tools to increase situational awareness.

Many countries are engaged in pilot projects to test such Smart Grid technologies²¹, for example: the island of Jeju, South Korea (Baker & McKenzie and Austrade 2010; KSGI 2010); Yangzhou, China (Xu et al. 2010); Yokohama, Japan (Hosaka 2010); Boulder, Colorado, U.S. (Battaglini et al. 2009); the TWENTIES (EC 2010) and EcoGrid EU projects in the European Union (Danish Technological Institute 2009; EcoGrid EU 2010); and planned smart grid applications for Masdar City, United Arab Emirates (Masdar 2010)²².

Due to their strong reliance on communication protocols, Smart Grids need logical (computer) security as well as the physical security required by conventional grids, which previously constituted the main security concern (Doran et al. 2010). This will provide obstacles to all countries, but especially those without strong governance systems in place.

2.3 COSTS AND BENEFITS

The scale of investment required to enhance today's grids to meet the demands of future power systems is considerable²³. Based on the IEA's New Policies Scenario, total investment in transmission and distribution is expected to reach USD 7.0 trillion (in year-2009 dollars) for the period 2010–2035 (IEA 2009)²⁴. According to the Brattle Group (2008), the U.S. electric utility industry is expected to invest USD 1.5–2.0 trillion in infrastructure within the next 20 years²⁵. Likewise, in East Africa alone, billions of dollars are required for supply and transmission infrastructure over the next two decades (BKS Acres 2005).

²⁰ Interoperability of equipment is a key requirement of Smart Grids.

²¹ India actively supports Smart Grid developments through the restructured accelerated power development and reforms programme (R-APDRP) (Balijepalli, Khaparde, and Gupta 2009).

²² For further information on pilot projects and policies refer to Doran et al. (2010). For a U.S. focus and information on dynamic pricing and pilot design principles refer to Faruqui et al. (2009). The consumer response to smart appliances combined with pricing signals was assessed in a project described in Chassin D. P. (2010).

²³ For context, overall total costs for providing energy access in sub-Saharan Africa are estimated to be approximately USD 25 billion per annum (Bazilian & Nussbaumer, et al. 2010).

²⁴ Barriers to smart grid investments are listed in MEF (2009).

²⁵ For comparison, the total asset value of the electricity sector in the U.S. is estimated to exceed USD 800 billion, with 30% in distribution and 10% in transmission facilities (DOE 2003).

In OECD countries, a significant share of these investments is expected to target the implementation and deployment of Smart Grids. However, the detailed monetary implications are not yet fully understood (IEA 2010) and cannot solely be reduced to infrastructure investments. Smart Grids redefine the roles of power sector stakeholders. Developing the required human and institutional capacities to best respond to stakeholder needs and responsibilities²⁶ will be essential for their successful implementation.

Smart Grids help to dynamically balance and optimize generation, delivery assets and loads. Associated key technical benefits include: improved reliability and resilience, cost-effective integration of variable resources and loads, increased efficiency of system operation, and optimised utilisation of both generation and grid primary assets²⁷. Smart Grids may deliver these benefits at potentially lower overall cost than would be possible under business-as-usual assumptions. In more detail, some of the benefits include:

Loss reduction: In current transmission and distribution systems, losses amount to approximately 9% of the electricity produced worldwide²⁸ (IEA 2008b; IEA 2010). While Africa's average losses of 11% are close to the global average (IEA 2010), many countries in sub-Saharan Africa are characterized by much higher system losses of up to 41%, including non-technical losses (UN-Energy Africa 2008). Higher technical losses are due to less efficient and poorly maintained equipment; higher non-technical losses are due to theft (IEA 2003).

Smart Grid technologies can help minimise technical losses in transmission by facilitating more effective reactive power compensation²⁹ and voltage control, for example. They can address distribution losses³⁰ through adaptive voltage control at substations and line drop compensation to levelize feeder voltages based on load (EPRI 2008). Non-technical losses such as power theft can be partially addressed with the help of smart metering infrastructure (M. Scott 2009)^{31,32}.

²⁶ A description of these needs and responsibilities can be found in ETP Smart Grids (2006).

²⁷ Based largely on improved communication and increased interoperability at all grid levels (FitzPatrick and Wollman 2010).

²⁸ Ranges vary from, for example, 5% in Japan (IEA 2008b) and 6% in the U.S. (EIA 2010) to 26% in India (IEA 2010). Distribution losses usually account for the largest share of total power delivery losses (ESMAP 2007). Substation transformers have been cited as the source of up to 40% of total grid losses (SCE 2010).

²⁹ For example, DC-to-AC current-controlled inverters can both supply and absorb reactive power only and do not participate in resonances, as capacitors do (Doran et al. 2010).

³⁰ Increasing the efficiency of European distribution transformers by 0.33% would have reduced losses by more than 100 TWh in 2000 and would result in savings of 200 TWh in 2030 (IEA 2003). For a sense of scale, the electricity generation of Australia in 2009 was 232 TWh (EIA 2010).

³¹ This was reported as one of the reasons for Italy's initiative to fit smart meters in 85% of Italian homes (M. Scott 2009). The Italian utility Enel reports annual cost savings of USD 750 million from their investments in the smart meter technologies, which were characterized by a payback period of technology, allowing it to recoup the infrastructure investment in just four years.

³² Additionally, monitoring of transformer loading and third party assessments of potential misuse will help tackle such power theft, which is often difficult to determine in developing countries as it can involve collusion with linesmen and meter readers.

Peak demand reduction: Active management of consumer demand through smart appliances and equipment will reduce the need for spinning reserve (DOE 2003) and expensive electricity supply to satisfy peak demand (GridWise Alliance 2010). This could be achieved using demand response programmes (Medina, Muller, and Roytelman 2010). A reduction of 1% in peak demand could result in cost reductions of 4%, equalling billions of dollars at system level (Doran et al. 2010).

Quality of supply: Smart Grids can significantly contribute to reducing costs of grid congestion, power outages and power quality disturbances³³. They do this by increasing the reliability and quality of supply for consumers with high requirements³⁴, while providing less reliable and lower quality power at reduced costs for consumers with lower requirements (IEA 2010). Increasingly efficient automated operations will also help address and anticipate disruptions (GridWise Alliance 2010).

Latent network capacity: A greater role for demand, and more sophisticated asset management and operation, can help enable the release of latent network capacity by building on advances in equipment monitoring and diagnostics as well as supportive standards³⁵ (U.K. House of Commons 2010). Technologies such as power flow control can have a huge impact on the effective utilization of network capacity under normal and contingency conditions.

In addition to technical benefits, potential benefits for the overall economy include:

Climate change mitigation: Direct and indirect benefits of Smart Grids offer the potential for yearly emission reductions of 0.9–2.2 Gt CO₂ per year by 2050 (IEA 2010). Direct benefits include reduced losses, accelerated deployment of energy efficiency programmes and direct feedback on energy usage. Indirect benefits include greater integration of renewable energy and facilitation of electric vehicles³⁶.

Job creation: Smart Grids should help trigger new investments and create new jobs. McNamara (2009) estimates that Smart Grid incentives worth USD 16 billion in the U.S. could trigger associated projects amounting to USD 64 billion. This would result in the direct creation of approximately 280,000 positions and the indirect creation of a substantially larger number of jobs.

Many of these potential Smart Grid benefits would be valid for sub-Saharan Africa, yet the concept and associated policies require refinement to optimise the cost/benefit balance in a sustainable manner.

³³ In the U.S., these costs are estimated to be in the range from USD 25– 80 billion annually (Willrich 2009).

³⁴ This would require utilities to prioritize the reliability of services dependent upon target group, such as emergency services, financial institutions, industries, consumers, and industry (Doran et al. 2010).

³⁵ For example, through weather-related operational security standards, which release latent network capacity under specific weather conditions (U.K. House of Commons 2010).

³⁶ Shifting demand, for example through electric vehicles, may in fact increase CO₂ emissions in systems where base load is met with more CO₂ intensive generation than peak load (Doran et al. 2010).

3. Smart and Just Grids for sub-Saharan Africa

Employing a subset of the advances in power systems provided by Smart Grids may enable sub-Saharan African countries to leapfrog traditional power systems to reach more effective solutions. This could accelerate national and regional electrification timeframes, while improving service and minimising costs and environmental impact. We introduce the term *Just Grids* to reflect the need for power systems to contribute towards equitable and inclusive global economic and social development. Given the specific needs of sub-Saharan Africa, it is obvious that a Smart Grid approach for this region cannot simply be a copy of practices in industrialised countries - the starting point, challenges and opportunities are too different. We consider how a redefined Smart Grid concept might usefully be implemented in sub-Saharan Africa.

3.1 REDEFINING THE CONCEPT

We broadly define the concept of Smart and Just Grids for sub-Saharan Africa as one that embraces all measures in support of immediate and future integration of advanced two-way communication, automation and control technologies into local, national or regional electricity infrastructure. The concept aims to optimise grid systems and their operation, integrate high levels of renewable energy penetration, and improve the reliability and efficiency of electricity supply. In addition to being smart, socially just³⁷ power systems are required in sub-Saharan Africa in order to guarantee access to modern energy services without marginalizing the poor³⁸.

In the future, Smart and Just Grids for sub-Saharan Africa could provide similar functionality to Smart Grids in industrialised countries at full deployment, even though they are likely to follow a different pathway and timeframe. The diversity of the electrification status in sub-Saharan Africa^{39,40} means that lessons learned from other regions may be directly applied in certain areas, while tailored solutions will be required for others. Constraints such as: a lack of good governance, limited investment capital, largely inadequate infrastructure, and a gap in well-trained power sector personnel are likely stifling innovative practices that could already be occurring organically⁴¹. While the costs for massively upgrading existing grids to Smart Grids may not be justifiable, the business case when investing in new infrastructure is significantly better, offering significant potential opportunities for sub-Saharan Africa. It will therefore be essential to prioritise

³⁷ According to Zajda, Majhanovich, and Rust (2006), social justice generally refers to, “an egalitarian society that is based on the principles of equality and solidarity, that understands and values human rights, and that recognizes the dignity of every human being”.

³⁸ Similarly, UNEP (2008) calls for a just transition to a sustainable, low-carbon economy to ensure that social aspects are equitably integrated into economic and environmental considerations, and that emerging opportunities are adequately shared among stakeholders.

³⁹ Wide variations in the energy sector can be demonstrated by per capita energy consumption, which varies from some 20 kgoe in Burundi to 860 kgoe in Zimbabwe, correlating well with respective GNP per capita (Karekezi 2002).

⁴⁰ This diversity is comparable to India, which may offer a significant potential to learn from its Smart Grid developments. Refer to Balijepalli, Khaparde, and Gupta (2009) and Balijepalli et al. (2010) for a focus on India’s related endeavours.

⁴¹ For example, the electrification of New York started with Thomas Edison’s effort to develop a successful business, covering the complete system of electric generation, distribution and appliances (the light bulb) (Brooks, Milford, and Schumacher 2004; ConEdison 2010).

specific smart solutions based on clearly defined functionalities that help reduce costs, promote economic growth and improve long-term sustainability.

We next characterise the approach to realising a Smart and Just Grid system into several elements and attempt to conceive of their application in sub-Saharan Africa.

Smart policies: Simplifying requirements for rural electrification schemes, defining common ground rules for integrating technologies and business practices, balancing cost recovery mechanisms for utilities, identifying better ways to support effective demand-side management, and developing new policies to support the integration of distributed generation. All such policies would need to be underpinned by well-defined performance goals and transparent metrics to ensure effective monitoring of anticipated benefits.

Focus for sub-Saharan Africa: Leveraging international Smart Grid frameworks, legislation, regulation and standards, and adjusting them to the sub-Saharan African context⁴² will be essential. New policies may need to diverge from international precedent, in order to prioritize access to affordable electricity services for the poor, respond to rapid demand growth and urbanisation, and reduce theft of electricity and utility assets. Such policies should enable access through flexible, no-regret electrification strategies that accommodate expansions of stand-alone systems, mini and national grids, and that support their integration⁴³.

Smart planning: Adjusting the grid to local circumstances and developing design principles that ensure an effective interoperability of existing and new grids, leading to even smarter networks over time.

Focus for sub-Saharan Africa: A balanced approach between regional grid integration, national grid enhancements and decentralised mini-grids is required. While smart mini-grids, such as those described in (Katiraei and Iravani 2006), may provide a short-term solution to rural electrification needs, their future integration into national and regional grids and *vice-versa* needs to be an integral consideration of power system planning⁴⁴.

Smart systems and operations: Guaranteeing the security and quality of supply through smart automation and control arrangements, building on load management and integration of distributed energy sources, for mini, national and regional grids, as shown in Ruiz et al. (2009).

Focus for sub-Saharan Africa: Country and locally appropriate supply quality standards will need to be derived. These may initially be less stringent than current practices in industrialised countries and may vary by class of service. Increasing the grid's load factor through demand side

⁴² Refer to Schwartz (2010) for further information on policy support required to deliver Smart Grid benefits.

⁴³ For example, in remote areas photovoltaic (PV) panels can provide a limited and, thus at times, limiting quantum of electricity for customers. At present, such customers are considered 'electrified'. In the case of mini- or national grid extensions with better power quality, such customers may either not be targeted or the photovoltaic system left unused, as current systems are often not designed to integrate such home circuits or local grids.

⁴⁴ For example, the Tres Amigas SuperStation in New Mexico, USA, will serve to improve grid reliability and solve voltage and stability issues by linking the three primary U.S. electricity transmission grids through high-voltage direct current converter technology (Alstom 2010).

management may also significantly help reduce costs, especially for rural electrification schemes (Matly 2010).

Smart technologies: Deploying proven smart technologies, optimising interoperability with emerging technologies, and developing future solutions to best address electrification needs (Massoud and Wollenberg 2005; You et al. 2002).

Focus for sub-Saharan Africa: The technology deployment path will vary widely at regional and country levels due to diverse needs and goals of different societies and markets. Defining these technology pathways and markets and verifying them through pilot projects will be important first steps.

Smart people: Building stakeholder capacity⁴⁵ to facilitate the transition to Smart Grids, to operate the grids, and to attract and actively engage the private sector and consumers so that as many people as possible profit from the transition.

Focus for sub-Saharan Africa: Educating consumers in sub-Saharan Africa about efficient electricity use whilst moving towards Smart Grids will be essential, especially for those who previously had no access. Training tools and materials about state-of-the-art power systems will also need to be widely disseminated. Specific attention needs to be paid to the training of off-grid communities so they can manage and maintain mini-grid systems in a sustainable fashion.

Responsibility for ensuring that grids are smart *and* just falls mainly on governments and utilities as a public good. The following Just Grid characteristics are especially relevant to sub-Saharan Africa:

Just access: Ensuring universal access to electricity by:

- Encouraging electricity to be tapped-off from larger grid extension projects to local customers *en-route*. Connections for large consumers are often the primary driver for grid extensions. Such extensions may offer a great opportunity to connect the under-served at the same time;
- Using grid technologies that can cope with fluctuating supply and demand in rural areas and thus increase supply quality of supply, for example by building on strategic load control and management instead of conventional load shedding;
- Focusing on accelerated access to key electricity services rather than just on access to electricity. Doing this in a 'smart' way may help governments deliver on their development agendas more effectively and at lower cost;
- Expanding service delivery under resource constraints by increasing the efficiency of electricity supply and use;
- Creating additional revenues for utilities through higher payment discipline, which would also encourage them to extend services to new customers.

Just billing and subsidies: Creating flexible tariff structures and payment schemes to ensure affordable and sustainable access to electricity services⁴⁶, by:

⁴⁵ This includes policy makers, government agencies, regulators, electricity network and service companies, traders, generators, finance institutions, technology providers, researchers and users.

- Realising the potential of Smart Grids to help lower prices⁴⁷ of electricity services by optimizing the utilization of grid assets, segmenting electricity markets according to reliability and quality requirements, minimising technical and non-technical losses by promoting smart and efficient appliances, and increasing cost-effective integration of renewable energy in remote areas⁴⁸;
- Providing additional support programmes to identify and foster productive uses of electricity to help ensure that low-income consumers can pay;
- Allowing for targeted subsidies through integrated smart billing to support 'basic' services such as food refrigeration, as opposed to 'luxury' services, like television.

There is clearly a vast array of Smart Grid elements available to support our redefined concept. They are not all immediately relevant, however, and some are either not developed enough or too expensive to be usefully deployed in the sub-Saharan African context in the short- to medium-term⁴⁹. Incorporating promising elements of future Smart and Just Grids in sub-Saharan Africa will require more than improved functionality, as has been observed with the adoption of other disruptive innovations (Christensen and Raynor 2003). A commercially successful business model including pricing, cost structure and sales process is key for a successful transition (Anthony 2004).

3.2 OPPORTUNITIES FOR LEAPFROGGING

The opportunity for Smart and Just Grids to leapfrog⁵⁰ traditional power systems may mean that they can offer even more exciting opportunities to developing countries than to industrialised ones. While some components of Smart Grids are a good basis for leapfrogging in the short-term, others will be essential for setting the preconditions required today for enabling a transition to smarter networks as the technologies mature in the future⁵¹. Avoiding technology lock-in will be crucial, as the economic lifetime of electric power equipment can be longer than 50 years (DOE 2003; ESMAP 2007). Thus, the faster the transition to the required enabling environments, the better.

⁴⁶ Refer to Kammen (in press) for energy pricing policies for consumers and producers aiming at the promotion of renewable energy and energy efficiency.

⁴⁷ The future price per kWh of electricity cannot be predicted with high certainty because electricity generation relies on various commodities traded on international markets. Smart Grids, however, can provide tools to enable consumers to manage electricity service net costs.

⁴⁸ This is especially true when diesel power generators are used: renewable energy provides a cost-competitive alternative, as fuel transport costs to provide diesel to remote locations in Africa are significantly higher than in most industrialised countries (Teravaninthorn and Raballand 2009). Costs for diesel power generation can range from USD 0.35 per kWh in Africa to more than USD 1 per kWh for Pacific islands and remote continental locations (UNIDO 2010). The use of locally available renewable resources increases supply security both in physical terms and in terms of pricing. This is especially important for supporting growth of electricity-dependent small and medium enterprises and industrial customers.

⁴⁹ We do however underline the importance of avoiding technology lock-in, to ensure that conditions set today will allow upgrading to future elements when the opportunity arises.

⁵⁰ A definition of technology leapfrogging can be found in Davison et al. (2000). Examples of leapfrogging in developing countries in the field of energy are mentioned in Goldemberg (1998).

⁵¹ For example, latest conductor technology and controls could be used for current greenfield developments to ensure long-term flexibility for integrating energy sources (IEA 2010).

3.2.1 THE ICT PRECEDENT

In the short term, we expect leapfrogging to occur mainly for the components based on information and communication technologies (ICT), which form an integral part of many Smart Grid systems. Africa has already had some excellent experiences in leapfrogging to more efficient ICT solutions. Although not a perfect analogy, the information revolution⁵² of the mid-1990s in sub-Saharan Africa linked to the use of mobile phones offers some useful lessons, because it gave people access to modern forms of communication without detouring via extensive conventional telephone networks.

Africa became the world's fastest growing cell phone market (LaFraniere 2005) with growth rates in the order of 300% per annum in countries like Kenya and Cameroon (Sebitosi and Okou 2009). Within 10 years, the number of mobile phone subscriptions in sub-Saharan Africa shot up from one per 100 people to 33 in 2008 (WB 2010). The actual number of users is expected to be much higher still, due to people sharing their mobile phones, especially in poor communities⁵³ (James and Versteeg 2007; N. Scott et al. 2004).

One reason for the mobile sector's great success was the failure of conventional telecommunication systems to meet consumer demand, both in terms of number of connections and quality (Wilson III and Wong 2003). This constitutes a parallel to the failure of current electricity networks in sub-Saharan Africa to meet the needs of millions of Africans. Another reason for the rapid diffusion of mobile phones was the lack of red-tape involved in registering for the pre-paid services that are used by 90% of mobile subscribers in sub-Saharan Africa (James and Versteeg 2007)⁵⁴. Pre-paid subscriptions address especially the needs of people with lower or irregular incomes, as no bank account, mail address, or fixed monthly fee are required (Gillwald 2005). Smart and Just Grids could take advantage of ICT infrastructure to implement similar payment schemes.

In addition to technological reasons for leapfrogging, market models that accompanied the mobile phone revolution such as sharing phones may serve as a precedent for Smart Grids. Other success factors, which may not translate as seamlessly to Smart Grids, were the relatively low initial investments and the quick installation of re-deployable assets, making assets less dependent on institutional frameworks and investor protection (Andonova 2006).

3.3 EFFECTS ON ENERGY PLANNING

The concept of Smart and Just Grids needs to be well integrated into national and regional energy planning⁵⁵ in order to take advantage of the possible opportunities for technological leapfrogging. Traditional electricity planning took demand growth as a given and only considered supply side options

⁵² Wilson III and Wong (2003) defined the information revolution as an institutional and policy revolution, highlighting the importance of private sector participation, foreign investment, competition and de-centralisation.

⁵³ Grameenphone has 6 million subscriptions in Bangladesh, 3% of which are for 'village phones', which are shared by a large number of users, and account for one-third of the traffic (The Economist 2006).

⁵⁴ Access rates are much higher than subscription rates, reaching almost 100% for some countries. This potential access is not directly beneficial for the large majority of the African people, who still cannot afford to pay for the services (James and Versteeg 2007).

⁵⁵ Munasinghe (1988) provides frameworks to guide sub-Saharan Africa's grid planning. Grid planning requirements are mentioned in Willrich (2009). An ideal objective function is defined in Bonbright, Danielsen, and Kamerschen (1988) and Bowen, Sparrow, and Yu (1999).

(Graeber, Spalding-Fecher, and Gonah 2005)⁵⁶. This traditional ‘predict and provide’ (Strbac 2010) approach⁵⁷ – predicting electricity requirements and designing the power systems accordingly – is adopted in sub-Saharan models such as the SAPP expansion plan (Bowen, Sparrow, and Yu 1999) and the East African Power Master Plan Study (BKS Acres 2005).

Development is no longer considered to be solely linked to steady energy demand growth (COMESA 2009a). Due to sustainability considerations, energy planning increasingly considers demand-side options (Shrestha and Marpaung 2006), social and environmental aspects, and associated costs (WB 2008; COMESA 2009a). The complex nature of modern electricity planning requires an approach that satisfies these often-conflicting goals (Swicher, Jannuzzi, and Redlinger 1997) as part of integrated resource planning (IRP) (D'Sa 2005)⁵⁸.

With a Smart Grid approach, planning increases in complexity as the grid evolves into an active layer between supply and demand. Planning for smart grids becomes an intricate exercise due to uncertainties about off-grid and distributed energy generation connections, as well as uncertainties about demand growth (MEF 2009)⁵⁹. In addition to optimizing electricity systems from a technical perspective, Just Grids need to be optimized from a development perspective. Ensuring services for marginalized and rural communities will often not be the most cost-effective solution, so new constraints (or different objective functions) need to be added to traditional least-cost optimisation models.

The required expansion and adaptation of the traditional approach to energy planning needs to include a more active role for demand, linkages with storage, and the integration of mini-grids into plans for grid expansion. An example of this – though limited – is presented in Howells et al. (2005)⁶⁰. In addition, modern energy planning needs to balance sustainable development plans carefully with regional energy integration and national and local Smart Grids. The importance of complex multi-criteria decision making will consequently continue to increase (MEF 2009; Hobbs 2000).

⁵⁶ In fact, rural electrification in industrialised countries basically happened through publicly supported local initiatives and independently of national or regional planning (Matly 2010).

⁵⁷ Several supportive modelling tools, which (to varying degrees) allow for the exploration of demand side management, are used for this type of analysis (Swicher, Jannuzzi, and Redlinger 1997). WASP, amongst others, constitutes a model that is frequently applied in Africa (ADICA 2001; Covarrubias 1979). Tools such as MESSAGE (IAEA 2009) and MARKAL (Alfstad 2005) are derived from the Häfele-Manne approach (Häfele and Manne 1975) and often used to model a “multi-regional” approach.

⁵⁸ D'Sa defines integrated resource planning (IRP) for the power sector as “an approach through which the estimated requirement for electricity services is met with a least-cost combination of supply and end-use efficiency measures, while incorporating concerns such as equity, environmental protection, reliability and other country-specific goals.”

⁵⁹ Accordingly, advanced system level modelling for Smart Grids has been identified as one of the Smart Grid research, development and demonstration priorities, according to the IEA (2010).

⁶⁰ Howells uses a tool based on MESSAGE, which, together with WASP and several other tools (IAEA 2009; HOMER 2010; ETSAP 2010) serves to examine the expansion of access to energy services.

3.4 EFFECTS ON REGULATION AND DESIGN PRACTICES

Present regulation often rewards utilities for delivering network primary assets rather than improving performance through more sophisticated management and advanced network technologies⁶¹. Thus, regulation can hinder Smart Grid developments that do not focus on investments in network assets.

Most current network design and operation practices centre on the historic deterministic N-1 approach that was developed in the late 1950s (Willis 2004). This has broadly helped deliver secure and reliable electricity services, alongside various other traditionally applied redundancy measures. These approaches can, however, impose major barriers for innovation in network operation and implementation of technically effective and economically efficient solutions that enhance the utilization of grid assets. Yet, the existing network and its standards are commonly taken as granted in research work, thus constraining the applicability of diverging approaches (Khator and Leung 1997).

While the “natural laws of transmission and distribution” described in Willis (2004) still apply, the future grids required in sub-Saharan Africa may offer fertile ground for a radical departure from such traditional regulation, grid design and operation practices, because of the significant infrastructure building requirements in the region. For example, Divan (2007) demonstrates significantly higher network capacity while meeting N-1 contingency constraints using economical distributed power flow control devices. Even higher utilisation is realized if the N-1 constraint is dropped. A relaxation of power quality and reliability standards based on the advances of Smart Grids may therefore enable sub-Saharan Africa to profit from the associated significant cost savings potential⁶².

Future network regulation and design is therefore required to facilitate the implementation of the economically best solutions. This will occur by balancing asset- and performance-based options⁶³, particularly those that involve responsive demand, generation and advanced network management techniques⁶⁴. In sub-Saharan Africa, novel regulatory regimes will also need to incentivise innovative ways of enhancing access to the grid.

3.5 EFFECTS ON OVERALL MARKET DESIGN

Innovation is required not only in technologies and regulation, but also in market models. Information systems infrastructure will help facilitate a shift to distributed control, with demand response becoming a key resource for delivering network flexibility and control. This will require significant changes in electricity market design principles, with a move away from traditional single-sided competition in large-scale generation.

⁶¹ In sub-Saharan Africa, laws governing the power sector and at times over-sophisticated standards sometimes originate back from colonial times (Matly 2010).

⁶² Such an approach could be supported by a range of advanced technologies such as dynamic line rating, coordinated special protection schemes, coordinated corrective power flow and voltage control techniques (potentially supported by wide area monitoring, protection and control technologies), and application of advanced decision making tools.

⁶³ Balijepalli, Khaparde, and Gupta (2009) underline the need for open, performance-based standards to ensure modularity and interoperability.

⁶⁴ An overview of how standards can support or hamper Smart Grids developments is provided in EPRI (2009).

Ultimately, a cost-effective system requires all players to interact competitively, optimising demand and supply (Strbac, Ramsay, and Moreno 2009). This would require a competitive, user-centred distributed energy marketplace based on real-time prices designed to integrate wholesale and retail energy markets.

While such markets are still mostly conceptual, in time, it will be important to understand and integrate demand into system design and operation for sub-Saharan Africa, supported by user-centric market models. This approach will be critical for enhancing access to electricity services, especially given the magnitude of the economic value of associated benefits such as enhanced asset utilization and improved operational efficiency.

3.6 TRANSMISSION AND DISTRIBUTION SYSTEMS

Crucial benefits of electricity grids result from a diversification of both demand and supply. National distribution networks of several thousand households are usually large enough to profit from demand diversity and associated significant savings in supply capacity requirements (Strbac, Jenkins, and Green 2006)⁶⁵.

Larger transmission networks are required to profit from diversification of supply (Bazilian and Roques 2008) by exploiting regional energy resources and infrastructure⁶⁶. Transmission expansions can significantly enhance the ability of the system to minimise fluctuations in demand and supply, increase the availability of back-up capacity (ECF 2010), and minimise the required spinning reserve. This is especially true when accommodating increased levels of intermittent renewable generation.

Critical voices like Sebitosi & Okou (2009) however regard grand infrastructure plans to link up the African continent's power grids as obsolete in the age of Smart Grids. Some aspects of this view are mirrored in the U.S. by Cavanagh (2008)⁶⁷ and Fox-Penner (2005)⁶⁸, who emphasise the importance of focusing on regional and sub-regional grids. However, as an example, high-capacity transmission corridors are still expected to form the backbone of the U.S. grid in 2030 (DOE 2003).

Sebitosi & Okou (2009) further suspect that super grids would "largely serve to extract untapped natural resources from the less developed to the more industrialized members". An example they cite comprises high voltage direct current (HVDC) lines to integrate renewable energy from North African countries into the European power system (Battaglini et al. 2009; DESERTEC Foundation 2009). Such plans seem to be the main focus of current discussions on modern grid investments in Africa. It remains to be seen to what extent the underserved in Africa will profit from such initiatives.

⁶⁵ The capacity of an electricity system supplying several thousand households is only about 10% of the total capacity that would be required if each individual household were to be self sufficient and provide its own generation capacity. A further increase in the number of households however only results in minimal savings.

⁶⁶ For the Southern African region, Graeber (2005) identified savings of \$2–4 billion over 20 years, equaling 5% of total system costs, when optimizing generation and transmission investments at a regional level. 60% of this savings potential can be attributed to lower operational costs.

⁶⁷ Cavanagh recommends that establishing a single interconnected 'national' grid in the U.S. should be less of a goal than upgrading the current three giant regional grids.

⁶⁸ Fox-Penner suggests subdividing regional grids into smaller grids building on direct-current lines to avoid cascading failures.

4. Near-term considerations

In line with findings from the ETP SmartGrids (2006), implementation of Smart Grids for sub-Saharan Africa will, *inter alia*, require: a toolbox of proven technical solutions, harmonised regulatory and commercial frameworks, shared technical standards and protocols, and supportive ICT systems. The successful interfacing of new and old designs will be especially important in view of future-proofing current grid infrastructure projects in a cost-effective way, to ensure compatibility with future plans to upgrade current systems to Smart Grids. Most importantly, Smart Grids require the development of human capacity to implement and manage the complex technologies involved and the enabling environments to overcome barriers⁶⁹, trigger required investments, and ultimately demonstrate the benefits of Smart and Just Grids. According to the IEA (2010), technical capacity has to be developed from a relatively low level in developing countries, lending further prioritisation to capacity-building initiatives.

4.1 APPLYING THE CONCEPT

Particular elements of Smart and Just Grids will offer tangible and direct benefits in the short-term. Their application will serve to test and enhance the concept in the sub-Saharan context, and help us understand how to expand its scope in the future. These elements include:

Transmission and substation design: Especially for longer transmission lines, the scale of technical losses can become considerable⁷⁰. Smart Grids can help reduce such losses, for example by improved power lines and transformers, as well as implementing regular maintenance schemes (Niez 2010). Wide-area monitoring and control⁷¹ can support the accurate information required for real-time decision making to respond better to disturbances within the system (SCE 2010). This will enhance utilization of primary grid infrastructure and contribute to a more efficient system operation. Some of the required advanced transmission technologies⁷² may target the more developed existing grids in sub-Saharan Africa, and may be disproportionate in areas with limited grid coverage.

Distribution system design: Distribution automation technologies can help improve power systems by extending intelligent control (SCE 2010). For example, smart sensors and flexible and intelligent switches and interrupters at critical points on distribution circuits will minimize the extent of outages and increase the speed of restoration, while keeping cost increases at a minimum. Smart distribution technologies allowing for increased levels of distributed generation will be especially important for addressing rural electrification needs and minimise connection costs. The planning and design of these networks will require

⁶⁹ Barriers for developing Smart Grids in South Africa can be found in Bipath (2010). Challenges, drivers and priorities in developing countries are mentioned in Bhargava (2010).

⁷⁰ For a sense of scale, Sebitosi and Okou (2009) note that, “the estimated amount of power that is lost during the delivery of 2000 MW from Cahora Bassa through the 1500 km line to South Africa is nearly equal to the entire consumption capacity of Mozambique, the host generating country”.

⁷¹ This represents a shift from the application of traditional local-based control in existing power systems. However, grid control and design techniques that incorporate such coordinated control are yet to be established.

⁷² In addition to synchrophasors, wide-area monitoring and control can build on intelligent electronic devices such as protective relays, programmable controllers and stand-alone digital fault recorders. Examples of applications include coordinated Volt-Ampere Reactive (VAR) control solutions (Yuan et al. 2010) and adaptive system islanding and resynchronisation (SCE 2010). Further, deploying low-sag, high-temperature conductors and dynamic line rating can significantly increase the electric current carrying capacity.

full horizon planning, i.e. a 20 year plus period. The development of these grids will be atypical but existing work on distribution planning may provide a canvas from which to work (Fletcher and Strunz 2007).

Non-technical losses in developing countries can often be attributed to uncollected debt, tampered meters and inconsistencies in billing due to corrupt meter readers or illegal connections (Niez 2010; Zheng 2007). Power theft often contributes significantly to overall system losses in developing countries⁷³, reducing the economic performance of utilities. High-voltage distribution lines can help prevent illegal connections and improve power quality and reliability (Niez 2010). Smart metering infrastructure with an independent transformer-loading based validation process can help reduce theft further. Additionally, meter-based tariffs incentivise an efficient use of electricity, which can result in considerable load reduction⁷⁴.

Smart mini- and micro-grids: Mini-, and especially micro-, grids with high shares of renewable energy are generally complex to implement, primarily because of fluctuating generation and a low load factor⁷⁵. The task of maintaining adequate power quality becomes a challenge, for example due to spikes associated with the starting current of motor loads (Makarand, Mukul, and Banerjee 2010) or the need to provide some form of back-up power. Smart components can help cushion such effects and better balance the overall system, through integrating new demand side management options. Costs of such systems may be further cut through the implementation of (DC) micro-grids, especially when combined with photovoltaic generation. While losses can be reduced through saving layers of DC/AC power conversion, the more expensive protective devices required for fault management and control, such as coordinated power converters, add complexity and outweigh some of the potential savings.

Demand side management: Demand side management options for large⁷⁶ consumer loads, like load control switches at industrial or institutional facilities, can contribute to optimising the quality of energy services and reducing load-shedding⁷⁷. This usually affects the poorest electricity consumers the most. Radio-controlled interruptible institutional water heaters or water pumping systems constitute just two examples for such load control. At the household level, smart appliances could also contribute. For example, smart refrigerators that hold enough thermal storage to withstand interruptions or avoid power use during peak loads could be deployed. Smart Grids would further allow the prioritisation of consumer loads according to public importance, guaranteeing a higher security of supply for buildings such as hospitals rather than for enterprises or households⁷⁸. As shown in Jazayeri et al. (2005), due consideration

⁷³ In addition to pure electricity theft, cable theft may constitute a significant problem. In various municipalities in South Africa, all-day street lighting is used as an early warning system, despite generation constraints (Niez 2010).

⁷⁴ In a mini-grid in Nicaragua, the abandonment of a flat-rate tariff after the installation of meters helped reduce the overall electricity load by 28% by encouraging a more conscious use of electricity, enabling the mini-grid to operate for longer (Casillas and Kammen).

⁷⁵ Energy conservation supply curves for measures regarding generation, metering and energy efficiency measures are provided in Casillas and Kammen (in press) for a mini-grid in Nicaragua.

⁷⁶ Large compared with the total capacity of the grid.

⁷⁷ In the Indian context, demand side management has also been proposed to ensure a higher quality of electricity supply for customers who regularly pay their bills, and less good quality for those who do not (Zheng 2007).

⁷⁸ This represents a shift from traditional preventive control philosophy to corrective, 'just in time', control approach. Benefits include enhanced utilization of grid assets and improved efficiency. Supportive new techniques and tools for system operation and design need to be developed and applied. For example, at industrial and institutional levels,

of price and system security is essential. As part of such load management, a Just Grid could ensure reliable and low-cost access for the poor during off-peak hours, for activities such as cooking, while curtailed access would be provided during times of higher demand⁷⁹. This could also encourage people to adopt energy-efficient practices for peak times, either because of higher tariffs or dependency on batteries⁸⁰.

Local charging stations: While rural electrification is a priority in many countries, it cannot be entirely equated with electricity access for the poor, as millions of people live near the grid but cannot afford a connection (Meier 2001; WB 1995). For these people, charging stations ensure a minimum level of access to electricity services, for example, for charging lanterns or batteries to power their radio or TV. Elaborating a successful business model⁸¹ for battery charging services at these stations may further contribute to increased power quality and reliability in mini-grids, by compensating power flow and voltage fluctuations. Charging stations could further minimise or eliminate the running of back-up diesel generators and spawn local businesses and jobs⁸². Another possibility would be the introduction of electric bicycles for taxi services; these could be charged at stations during off-peak hours, combining income generation with demand side management⁸³.

Billing schemes: As many Smart Grid components build on ICT, they might profit from 'piggybacking' on future telecom service expansions, such as the provision of electricity consumption information via mobile phones. Charging prepaid consumption credits⁸⁴ via mobile phones using scratch cards or comparable devices may help address the specific needs of the poor and reduce administrative costs related to meter readings and billing⁸⁵. A basic time-of-use pricing scheme at household level may easily be introduced in sub-Saharan Africa to help balance demand⁸⁶. Conceivably, tariffs may even be delineated by service to allow for targeted subsidies. For energy-intensive industries, real-time pricing may be considered. In addition, on-bill financing⁸⁷ of energy-efficient appliances⁸⁸ may be an important tool to help consumers overcome high upfront costs.

under-frequency protective relays for heating, cooling and motor loads can provide significant support for grid operation.

⁷⁹ Such demand would come from loads that require higher reliability, such as industrial and commercial usage.

⁸⁰ This has been observed with water supply schemes, where communities adjust their behaviour to access a critical but economical resource. People carry out water-intensive functions such as cleaning clothes during hours of supply, and reserve activities that need less water, such as cooking, for times with no supply.

⁸¹ This model would need to cover the logistics of battery ownership, management and charging.

⁸² For example, charging services, mills for grinding grain, IT services or community meeting places.

⁸³ Due to strong policy support, China has four times more electric bicycles than cars on its roads, with 21 million bicycles bought in 2008 alone, at prices typically below USD 300 (Ramzy 2009). By controlling their charging time they could become one element of a Smart Grid.

⁸⁴ Botswana and other countries were already using pre-paid meters in the 1980s (McDonald 2009). Refer to Niez (2010) for information on the introduction of prepaid electricity meters under South Africa's Integrated National Electrification Programme.

⁸⁵ For customers with a telecom contract, the electricity bill may as well be charged to the monthly telephone bill.

⁸⁶ As already outlined as a demand side management option, this may include special schemes where low-cost electricity is provided at off-peak hours to ensure affordable access for the poor, but with lower reliability during the rest of the day. Loads requiring higher reliability would need to pay a higher tariff for this privilege.

⁸⁷ Refer to (Kammen) for further information on on-bill financing.

Information systems architecture: Smart data management tools will help utilities distil relevant information in a manageable and understandable format. Diagnostic software will further help monitor the health of grid assets, predict problems in power distribution, and initiate corrective action. The required architecture must ensure interoperability and enable a smooth transition from existing to future power systems (SCE 2010). Special attention to security issues will be required in countries with limited robust governance regimes. User-friendly interfaces, such as cell-phone billing and transparent metering, will be equally important to engage customers successfully.

4.2 ENSURING COORDINATED ACTION

Regardless of which specific aspects of Smart and Just Grids for sub-Saharan Africa are pursued, international cooperation will be essential⁸⁹. Such cooperation would further benefit from the close involvement of organisations such as existing Smart Grid alliances in industrialised countries (e.g. ETP Smart Grids, GridWise Alliance) and nascent bodies like the International Smart Grid Action Network or the Global Smart Grid Federation, both announced at the First Clean Energy Ministerial (2010). South–South Cooperation should form an integral element of the required international action as many sub-Saharan African countries face similar challenges to the developing and emerging economies of countries such as India⁹⁰.

More specifically, Smart and Just Grids for sub-Saharan Africa can profit from international cooperation in the following areas:

Analysis of potential and roadmaps: Identify sub-Saharan Africa’s potential to profit from Smart and Just Grids, including an assessment of associated costs and benefits. Develop a road map up to 2030 including identification of technology solutions that can be rapidly and cost-effectively deployed in the short-term. This roadmap could be aligned with similar efforts by the IEA.

Country assessments: Provide international support for preliminary assessment of the power sectors and their needs, focusing on policy, regulatory, legal, institutional and commercial frameworks, energy planning tools, transmission and distribution system design, operational modalities, technologies and technical standards. Based on this assessment, develop country-specific business and development cases for Smart and Just Grids, with clearly defined technology transfer routes. Prioritise investments in specific smart elements with clearly defined mechanisms for return on investment⁹¹.

Power system design: Develop and deploy internationally supported open-source or widely available modelling tools and capacities for power system design and operation. Adjust power system design to the

⁸⁸ In a mini-grid in Nicaragua, the introduction of compact fluorescent lights helped to cut demand by 17%, which meant the mini-grid could operate for longer (Casillas and Kammen).

⁸⁹ According to Bipath (2010), international cooperation for Smart Grids is expected to focus on standardisation, cybersecurity and interoperability.

⁹⁰ Balijepalli, Khaparde, and Gupta (2009) report the detailed requirements and needs for Smart Grids in India.

⁹¹ While we emphasise the importance of business case development, it needs to be recognised that many historical infrastructure projects were based on home-grown ‘nation-building’ initiatives.

specific context: simple planning tools can address urgent electrification needs in, for example, post-conflict areas; more sophisticated tools are required to upgrade extensive existing power systems to Smart and Just Grids. It is critically important that the architecture developed enables future system upgrades without adding significant costs during early implementation stages.

Pilot projects: Implement joint pilot projects based on identified fast-track solutions. As the deployment of smart electricity systems redefines the roles of stakeholders, these pilot projects will help understand stakeholder behavior within these redefined roles and test the markets before engaging in massive rollouts. Remote rural electrification schemes with higher penetration rates of renewable energy sources would serve as a particularly good starting point for testing the concept of Smart and Just (mini-) Grids.

Enabling environments: Help promote supportive policy, regulatory, institutional, legal and commercial frameworks, including the required codes and standards. Sub-Saharan Africa especially can profit from ongoing efforts in industrialised countries to adjust related network standards. Additionally, legislation precedents can be employed to help reduce electricity theft⁹². Further, international design competitions supported by financial reward could support business case development by helping to highlight challenges and develop innovative solutions.

Capacity-building initiatives: Based on skills assessments, train key stakeholders such as Ministries in charge of energy issues, power pool representatives, energy regulators and national system operators on the Smart and Just Grid concept. Developing the asset management capacities of African utilities and energy entrepreneurs to maintain technical systems and equipment will be vital for ensuring the sustainable deployment of Smart and Just Grids. Concerted international efforts to develop centres of competency in power engineering for selected sub-Saharan African countries will help build up the required regional and national expertise.

For a successful transition towards smart and just energy systems, such international cooperation will need to be complemented by close engagement with regional and national stakeholders, from policy and institutional levels to generators, consumers, power equipment manufacturers and ICT providers. While Smart and Just Grids require strong public commitment, including funding, the private sector as the main engine of economic growth has an essential role in supporting related initiatives in sub-Saharan Africa. Creating reliable investment environments will help to engage all key players effectively.

5. Conclusion

Sub-Saharan Africa is characterised by significant electricity-related challenges in terms of resources, infrastructure, cost and sustainability. A number of regional and national energy strategies, policies and targets aim to address these challenges and accelerate electrification rates, although they have yet to translate into significant implementation measures. Finding ways to enhance future power systems represents a key task for governments, regional power pools and utilities. Some approaches may enable

⁹² China's major reform of the rural power management system in 1988, combined with rural grid enhancements, helped reduce losses in low-voltage grids by 30–45% and consequently lowered electricity prices. Refer to Niez (2010) for further information. For another example, refer to India's 2003 Electricity Act, which heavily penalizes electricity theft (Niez 2010).

sub-Saharan Africa to leapfrog traditional power systems practices and move to Smart Grid elements in the short term. Others will require preconditions to be established in order to avoid technology lock-in and ensure compatibility with new concepts and technologies in the future.

We have described an augmentation of the concept of Smart Grid and presented a broad definition of Smart and Just Grids for sub-Saharan Africa, embracing the need to guarantee inclusive access to modern energy services without marginalizing the poor. This refined concept will need to be carefully integrated into national and regional energy planning, regulation and markets, in order to balance the costs and benefits of regional grid integration with those of national and local Smart Grids.

We have further identified some elements of Smart and Just Grids that offer tangible and direct benefits in the short-term. Exploring the concept of Smart and Just Grids by implementing these elements and suggested areas for international cooperation will be essential for realising significant future benefits. These will go well beyond improved voltage and frequency control.

From an economic perspective, reliable energy supply through Smart and Just Grids will help foster economic growth. From an environmental perspective, Smart Grids will support and accelerate a cost-effective transition to low-carbon economies by lowering greenhouse gas emissions. Finally and most importantly, from a societal perspective, access to electricity is a prerequisite towards development as it is linked to many aspects of the development agenda, including access to better health services, education and security.

The massive electricity infrastructure requirements in sub-Saharan Africa offer a unique opportunity to learn from grid developments in industrialised countries and move forward without necessarily repeating all previous development stages. We should take advantage of this significant opportunity to ensure that sub-Saharan Africa's future grid is designed in a way that is both smart and just.

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