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Discussion

Energy access scenarios to 2030 for the power sector in sub-Saharan Africa

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ABSTRACT

In order to reach a goal of universal access to modern energy services in Africa by 2030, consideration of various electricity sector pathways is required to help inform policy-makers and investors, and help guide power system design. To that end, and building on existing tools and analysis, we present several 'high-level', transparent, and economy-wide scenarios for the sub-Saharan African power sector to 2030. We construct these simple scenarios against the backdrop of historical trends and various interpretations of universal access. They are designed to provide the international community with an indication of the overall scale of the effort required – one aspect of the many inputs required. We find that most existing projections, using typical long-term forecasting methods for power planning, show roughly a threefold increase in installed generation capacity occurring by 2030, but more than a tenfold increase would likely be required to provide for full access – even at relatively modest levels of electricity consumption. This equates to approximately a 13% average annual growth rate, compared to a historical one (in the last two decades) of 1.7%.

1. Introduction

The provision of reliable, secure, and affordable energy services are central to addressing many of today's global development challenges, including poverty, inequality, climate change, food security, health and education. They are also required for wealth creation and economic development. The link between energy and the Millennium Development Goals (MDGs) has been discussed extensively in the literature (e.g., Modi et al., 2005; AGECC, 2010) and energy poverty is acknowledged as undermining achievement of the MDGs. The obstacles to widespread energy access, and specifically electricity access, are largely well known (i.e., financing, planning, governance, and human and institutional capabilities), yet not trivial to overcome. While there are no fundamental technical obstacles preventing universal energy access, there is, however, a lack of effective institutions, good business models, transparent governance, and appropriate legal and regulatory frameworks. This work is aimed at improving understanding about the scale of reaching universal access to electricity services in sub-Saharan Africa (SSA) and clarifying the role of the international community. It is, of course, only one aspect of the information required.

Current actions to eliminate energy poverty are falling short both in terms of scale and pace. In fact, if current trends continue, more people in Africa will be without access to modern energy services in 2030 than today (IEA, UNDP and UNIDO, 2010). Changing this requires global political commitment that goes

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beyond abstract political statements and sets out actions and associated benchmarks (Bazilian et al., 2010b). To that end, a goal of achieving sustainable energy for all, with a 2030 target of providing universal access to modern energy services, was put forth to the international community in 2010 by the United Nations Secretary-General's Advisory Group on Energy and Climate Change (AGECC, 2010)[1]. Supporting this goal, the United Nations General Assembly declared 2012 as the *International Year for Sustainable Energy for All*[2]. Thus, the time is ripe for scaling-up efforts.

To help inform debate, investment, and more detailed analysis, we focus on the economy-wide[3] electricity sector, and review the literature and present several simple and transparent scenarios for the sub-Saharan African (SSA) power sector to 2030. We mainly focus on those countries with very low rates of access to electricity services and so generally exclude the Republic of South Africa (RSA) from the analysis. The scenarios are simple because we generally employ simplified power system planning and forecasting methods, and focus primarily on one metric, namely, installed generation capacity. (As a result, issues of cost are generally outside the scope of this paper.) They are transparent because we clearly identify all inputs and parameters, as well as present ranges for our assumptions. We focus on generation capacity as a useful metric to communicate the issue, as it is more easily understandable to a non-specialist audience than, say, electricity demand. (In other words, it is easier to discuss electricity supply issues in terms of power plants (i.e., MW) than electrical power (i.e., TWh).) This work is aimed at helping at improving understanding about the scale of reaching universal access to electricity services in SSA and the resultant decision-making processes. Hence, it serves to refine input assumptions, parameters, and the nature of outputs from future, more detailed analysis, while informing decision-making today.

Section 2 briefly reviews the related literature and discusses various approaches for energy planning and demand projections. It also touches upon the associated issues of capacity building and data paucity. In Section 3, a concise historical overview of power systems in Africa is presented[4]. Related published or on-going modeling efforts are described in Section 4. In Section 5, we present some simple energy access scenarios. Finally, Section 6 presents conclusions. As the approach in this paper is at a relatively high level of abstraction, we provide extensive references throughout (where there a many references, we generally cite them in footnotes). We also provide additional and complementary analysis in the Annexes (1–5) related to alternative estimates for generation requirements, costing, and more detailed analyses specific to household electricity needs[5].

2. Energy planning

Comprehensive energy systems planning aims at ensuring that energy-related policy and investment decisions consider all possible energy supply and demand side options, and are consistent with broader national goals (e.g., sustainable development)[6]. A necessary prerequisite, however, is the existence of national energy planning capability (capacity). Energy planning capacity increases a country's ability to anticipate and respond to the rapid changes occurring, and new issues and opportunities arising. The value of this asset increases over time, as experts gain experience in applying their skills, build the local knowledge base and forge relationships with stakeholders from diverse sectors. Inadequate national planning capability and consequent poor policy and investment decisions in the past have led to disparate level of access to modern energy services. Energy planning is also a matter that extends beyond national borders, especially for smaller countries with underdeveloped energy resource potentials (e.g., hydropower) or where sharing infrastructure with neighbours would provide economies-of-scale.

There is a large ongoing discussion around market reform and liberalization in SSA power systems. (As an ilustration of this, Eberhard et al. (2011) dedicate an entire chapter on reforming State-owned enterprises.) Over the last 20 years many developing countries have adopted far-reaching policies that encourage liberalization and privatization, often at the behest of major international funders and development organizations. While these policies have often improved the "health" of individual national utilities, with very few exceptions they have not led to dramatic increases in energy access, for the simple reason that meeting the electricity needs of the poorest is not very profitable for utilities. This debate coincided with the same dialogue that occurred in the OECD over the last two decades; in these industrialised countries it too has had very mixed results. The clear benefits of liberalizing these mostly fragile markets are unclear, where it has been ideologically pushed on to these countries, it is often to their detriment, despite good intentions[7].

Like many facets of public policy, energy policy has been informed by recourse to analytical models[8]. However, the outputs, temporal and spatial scope, sophistication, language, assumptions, system boundaries, and theoretical frameworks of these analytical tools vary dramatically. Thus, the results of these analyses require some considerable level of filtration and translation in order to appropriately inform design and implementation of government policy. *Apropos* of this, Munson (2004) notes that there is a, "disconnect between the questions policy makers want answered and the results provided by modelling exercises". Power system analyses can be

[1] Two other targets, informed by AGECC and further consultation, together comprise a wider sustainable energy goal. The other two are: to double the historic rate of improvement in energy efficiency, and double the percentage of renewable energy in the overall fuel mix by 2030.

[2] For more information: http://www.sustainableenergyforall.org.

[3] The analysis includes all sectors of the economy. This is a required clarification as many pieces of related analysis only consider household energy demand.

[4] In general we focus on historical data from the past 20 years.

[5] The results in the various Annexes are not directly comparable as they employ different methodologies, parameters, etc.

[6] The literature on energy planning is vast (See e.g., Alarcon-Rodriguez et al., 2010; Alcamo, 1984; Allan and Billinton, 1988; Andersson, 1988; Antunes et al., 2004; Balachandra and Chandru, 1999; Barda et al., 1990; Berry and Hirst, 1990; Boulanger and Bréchet, 2005; Dijk and Kok, 1987; D'Sa, 2005; El-Fouly et al., 2008; Elshafei, 1979; Garcia et al., 2008; Ghanadan and Koomey, 2005; Güven, 1994; Hart and Jacobson, 2011; Heinrich et al., 2007; Kobos et al., 2006; Pokharel and Chandrashekar, 1998; Psarras et al., 1990; Rachmatullah et al., 2007; Rath-Nagel and Voss, 1981; Samouilidis and Berahas, 1983; Shrestha and Bhattarai, 1994; Silva and Nakata, 2009; Spinney and Watkins, 1996; St. Denis and Parker, 2009; Turkson, 1990; Voropai and Ivanova, 2002, and Wu et al., 2000).

[7] See e.g., Arango and Larsen, 2011; Auriol and Blanc, 2009; Dubash, 2003; Gillwald, 2005; Gratwick and Eberhard, 2008; Gualberti et al., 2009; Habtetsion and Tsighe, 2007; Haselip, 2007; Haselip and Hilson, 2005; Haselip and Potter, 2010; Jamasb, 2006; Malgas and Eberhard, 2011; Mebratu and Wamukonya, 2007; Nagayama, 2007; Nagayama, 2009; Nagayama and Kashiwagi, 2007; Nyoike, 2002; Patlitzianas et al., 2006; Pineau, 2007; Sioshansi, 2006; Turkson and Wohlgemuth, 2001; Williams and Ghanadan, 2006, and Zhang et al., 2005.

[8] Creating a taxonomy of the various energy models is difficult, although there is a wide literature available (e.g., IPCC, 2001; Weyant, 2004; Edenhofer, 2005; Nakata, 2004; Barker et al., 2006, and Fisher et al., 2007). Reviews are available (see Huntington (2002) or Nakata (2004)) which focus on the primary energy models used in practice (e.g., WASP, POLES, PRIMES, MARKAL, AMIGA, MERGE, MESSAGE, LEAP, NEMS, ENPEP, MIT-EPPA, G3, GTEM, and MACRO).

considered a sub-set of energy system modelling. For the power sector, integrated resource planning models (IRP) are often used[9].

Power system analyses, management and planning are used over various timeframes – from sub-second (load balancing) to several decades (capacity expansion). The planning methodologies employed and the aims of the analytical work vary accordingly. We focus on the long-term, i.e. over a 5–20 year time horizon, the foundation of which is normally a set of electricity (or energy) demand projections. Electricity capacity expansion planning generally tends to be based on some type of least-cost optimisation given various constraints that mirror existing physical infrastructure conditions, access to finance, public policy regarding environment protection or energy security considerations. Many modern mathematical techniques ranging from fuzzy logic, to evolutionary programming, to mixed integer linear programming and multi-objective optimisation are in general use in government planning offices and utilities worldwide[10]. A trend towards accommodating various aspects of uncertainty and liberalized markets is apparent in recent research in this subject. However, for most power systems in sub-Saharan Africa, a high level of methodological sophistication may not be required to get underway with generation and infrastructure planning.

A clear issue that emerges in energy planning relates to data paucity and quality (Bazilian et al., 2010a). Energy modeling, which lies at the heart of most planning processes, tends to be very data-intensive, which creates obstacles for many countries (Howells et al., 2010). A reliable and comprehensive information base is required to set targets and monitor outcomes, to design strategies and policies, to make evidence-based decisions, and to enable consumers to make informed choices[11]. Moreover, poor and inconsistent national statistics limit cross-country analysis and undermine efforts to implement global or regional programmes. Still, a lack of data, should not be used as a justification for delaying building national energy planning capability and developing energy plans. Missing data can be derived from first principles or estimates, and used as placeholders until better data become available[12].

2.1. Energy demand projections

Energy demand projections represent a crucial component in most planning endeavours. As mentioned, different tools and methods (see Table 1) of various degree of complexity are used to estimate future demand[13].

The various approaches have their respective strengths and weaknesses. The choice of the appropriate method is contingent on a number of factors, notably on the nature and the availability of underlying data as well as on the purpose of the analysis and timeframe. For many of the long-term planning exercises conducted in SSA, demand projections are based on some econometric relationship to income (GDP) and population growth projections, along with an elasticity relationship. In addition, some have explicit terms for household connections, and large point demands (as an example, see Eq. (1)) (PIDA, 2011).

Table 1
Selected methods utilised for energy demand projections (adapted from: McDowall and Eames (2006) and Thomas (2006))[14]

Type	Description
Trend method	Non-causal model, i.e. it does not explicitly explain how the projected variable is determined, which is purely a function of time (e.g., x% increase per year).
End-use method (or engineering based method)	Approach based on energy usage patterns of appliances and systems.
Agent-based models	Class of computational models for simulating the actions and interactions of autonomous agents (both individual and collective entities) with a view to assessing their effects on the system as a whole. The models simulate the simultaneous operations and interactions of multiple agents, in an attempt to re-create and predict the appearance of complex phenomena.
Time series method	Projections solely based on historical patterns in the data.
Econometric method	Standard statistical tools are employed to produce a mathematical representation of the energy demand as a function of a series of variables (e.g., population, GDP). The functions derived can then be used to project the demand into the future, assuming that the causal relationships remain unchanged over time. Alternatively causal relationships are guided by normative of policy objectives.
Neural network techniques	Techniques which are able to capture and represent complex input/output relationships, both linear and non-linear. The advantage is the ability to learn these relationships directly from the data being modeled. Usually used for short-term load forecasting.

$$D_t = D_{t-1}\left(\varepsilon\frac{\Delta GDP}{GDP}+1\right)+k\cdot C_t+\Delta M_t \quad (1)$$

Where:

D is the unconstrained demand;

ε is the GDP elasticity of electricity demand; k is the average annual consumption of electricity of one household;

C_t is the number of new connections in year t; and

ΔM_t is the additional demand from new large demand points, e.g., from the natural resources extraction sector in year t to reflect the significant impact on the demand of new mine developments, (provided they draw their electricity from the power grid)[15].

These well-understood techniques, based on aggregates such as GDP and exogenous inputs like future annual grid connections of households, are not ideally suited for situations where much of the population lacks access to electricity services. In these cases,

[9] IRP has a long history as a process and an associated set of analytical tools for expanding the traditional concept of least-cost utility planning (Swisher et al., 1997).

[10] See e.g., Botterud and Korpas, 2007; Dodu and Merlin, 1981; Elkarmi et al., 2010; Hu et al., in press n.d.; Levitin and Lisniasnski, 1999; Manso and DaSilva, 2004; Malcolm and Zenios, 1994; Sanghvi, 1984; Smith and Villegas, 1997; Tekiner et al., 2010, and Unsihuay-Vila et al., 2011.

[11] See e.g., ICSU (2007).

[12] Interestingly, the availability of good quality public domain data has, in some cases, also been hampered by market liberalization in the energy sector over the past 20 years, with the consequence that some of the data most useful to national energy planners is now proprietary.

[13] See e.g., Abraham and Nath, 2001; Adams and Shachmurove, 2008; Basu et al., 1991; Ediger and Tatlidil, 2002; García-Ascanio and Maté, 2010; Pappas et al., 2008; Price and Sharp, 1985 and Ünler, 2008.

[14] See also Section 3 in SNC Lavalin (2010) for a description of various demand forecasting techniques used in Africa.

[15] Large energy-intensive industries (e.g., smelting, water desalinization) require a great amount of electricity. Mining is particularly important in many countries in sub-Saharan Africa. For instance, the mining sector accounts for almost half of the total electricity demand in Guinea (Nexant, 2004). Mining activities are expected to expand rapidly in Africa in the next few years, particularly in West Africa and to a lesser extent in Central Africa. The addition to the grid of a large point consumer can be a problem where the grid is weak and the interconnection low. For these reasons, large demand projects commonly include some endogenous power generation.

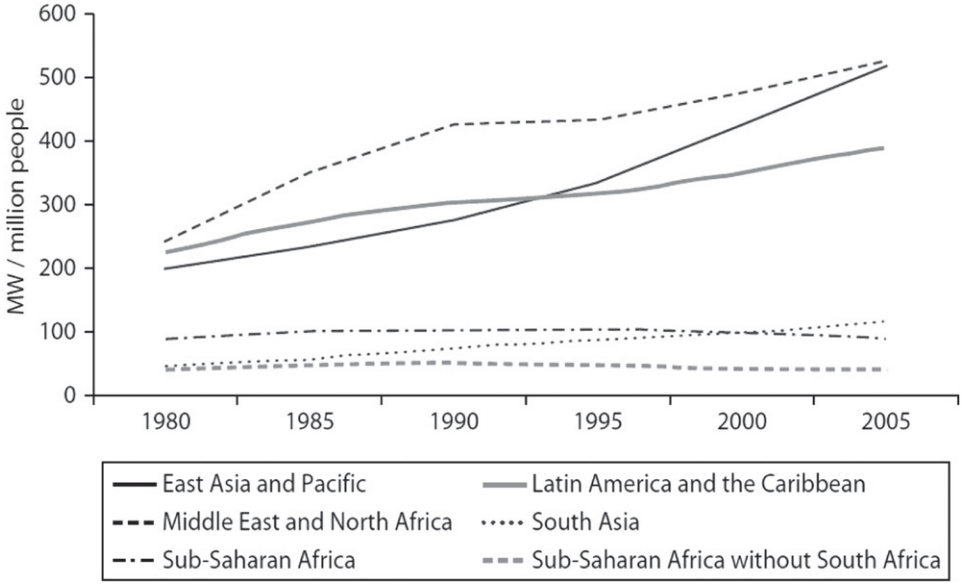

Fig. 1. MWs installed per one million people by region (Eberhard et al., 2011).

a different type of approach is needed, for example solving for a future goal and back-casting, rather than forecasting based on historical trends. Ensuring that the type of analysis is appropriate for the policy and investment questions is essential[16]. It has been argued that in a severely supply-constrained electricity system, demand projections are less important than capacity expansion planning and associated finance. In other words, in typical developing country situations additional supply would create its own demand (Langlois et al., 2011).

3. Historical energy trends

Sub-Saharan Africa suffers acutely from a lack of access to electricity and poor quality of supply, in terms of cost and reliability, where it does exist. There are approximately 580 million people on the continent without access (IEA, UNDP and UNIDO, 2010) – the bulk of them living in rural areas. Overall the electrification rate in SSA is around 30% (60% urban; 14% rural) (IEA, UNDP and UNIDO, 2010). Full analysis of the energy landscape for Africa is available from several sources (e.g., Foster and Briceño-Garmendia, 2010; and Eberhard et al., 2011 [17]). The recent power system academic literature on the topic of Africa is dominated by discussions around solar power in North Africa. Also, much of the literature on the power sector in SSA is not surprisingly focused on the Republic of South Africa (RSA)[18]. However, there has been a steady group of dedicated researchers focusing on SSA[19] or on particular SSA countries[20]. Still, there is a relatively small existing literature on scenarios for the power sector in sub-Saharan Africa[21].

The total average per capita annual consumption in SSA (excluding RSA[22]) is around 155 kWh (based on 2008 EIA data)[23]. These figures are minute compared to South Africa (4770 kWh/per capita) or Organisation for Economic Co-operation and Development (OECD) countries[24]. To get a sense of the scale, Eberhard et al. (2011) note that, "Installed capacity [in Africa] will need to grow by more than 10 percent annually just to meet Africa's suppressed demand[25], keep pace with projected economic growth, and provide additional capacity to support efforts to expand electrification…-Most new capacity would be used to meet non-residential demands from the commercial and industrial sectors."

[16] The challenge is that funding bodies often insist that sophisticated models be used in analyzing potential investments, and take comfort in tools and approaches more suitable for OECD countries.

[17] In addition, the Africa Infrastructure Country Diagnostic Programme (AICD) is an especially important contribution to knowledge in this area. The Africa Infrastructure Country Diagnostic (AICD) was an unprecedented knowledge program on Africa's infrastructure that grew out of the pledge by the G8 Summit of 2005 at Gleneagles to substantially increase ODA assistance to Africa. The AICD study was founded on the recognition that sub-Saharan Africa (SSA) suffers from a very weak infrastructural base, and that this is a key factor in the SSA region failing to realize its full potential for economic growth, international trade, and poverty reduction (see http://www.infrastructureafrica.org).

[18] See e.g., Auriol and Blanc, 2009; Davidson and Mwakasonda, 2004; Davis, 1998; Graeber and Spalding-Fecher; 2000, Inglesi-Lotz, 2011; Inglesi-Lotz and Blignaut, in press n.d.; Meyer and Greyvenstein, 1991; Odhiambo, 2009; Pereira et al., 2011; Sigauke and Chikobvu, in press n.d.; Steinbuks and Foster, 2010; Tewari and Shah, 2003; Thom, 2000; Winkler, 2005; Ziramba, 2008; Eskom, 2009; GoSA, 2010; World Bank, 2007 and Bazilian et al., 2011.

[19] See e.g., Ben-Yaacov, 1979; Bugaje, 2006; Chineke and Ezike, 2010; Deichmann et al., 2011; Girod and Percebois, 1998; Gnansounou et al., 2007; Inglesi, 2010; Karekezi and Kimani, 2002; Lazenby and Jones, 1987; Maboke and Kachienga, 2008; Murphy, 2001; Pineau, 2008; Sebitosi, 2008; Sebitosi and Okou, 2010; Sebitosi et al., 2006a; Sebitosi et al., 2006b; Turkson and Wohlgemuth, 2001; Wolde-Rufae, 2006 and UNECA and UNEP, 2007.

[20] See e.g., Akinlo, 2009; Amobi, 2007; Buchholz and Da Silva, 2010; Gujba et al., 2011; Kouakou, 2011; Mangwengwende, 2002; Mbohwa, n.d.; Neelsen and Peters, 2011; Nhete, 2007; Nyoike, 2002; Pineau, 2002; Pineau, 2007; Norad, 2009 and Rowlands, 1994.

[21] See e.g., Adam and Moodley, 1993; Bekker et al., 2008; Brew-Hammond and Kemausuor, 2009; Deichmann et al., 2011; Garrett, 1994; Gnansounou et al., 2007; Gujba et al., 2011; Maboke and Kachienga, 2008; Winkler et al., 2009; Karakezi, 2006; Davidson, 2002; Davidson, 2004 and Sparrow et al., 2003.

[22] We often focus on SSA without South Africa to give a more focused perspective on energy access; as South Africa has around a 75% rate of access to electricity.

[23] This figure is for the entire economy. Eberhard et al. (2011) cites this as 124 kWh/capita (perhaps the discrepancy arises due to different base year data sets).

[24] e.g., Chile: 3327 kWh/per capita; Germany: 7148 kWh/per capita; USA: 13,647 kWh/per capita (IEA, 2011).

[25] Suppressed demand refers to the difference between notional demand and supply (Eberhard et al., 2011; p.55).

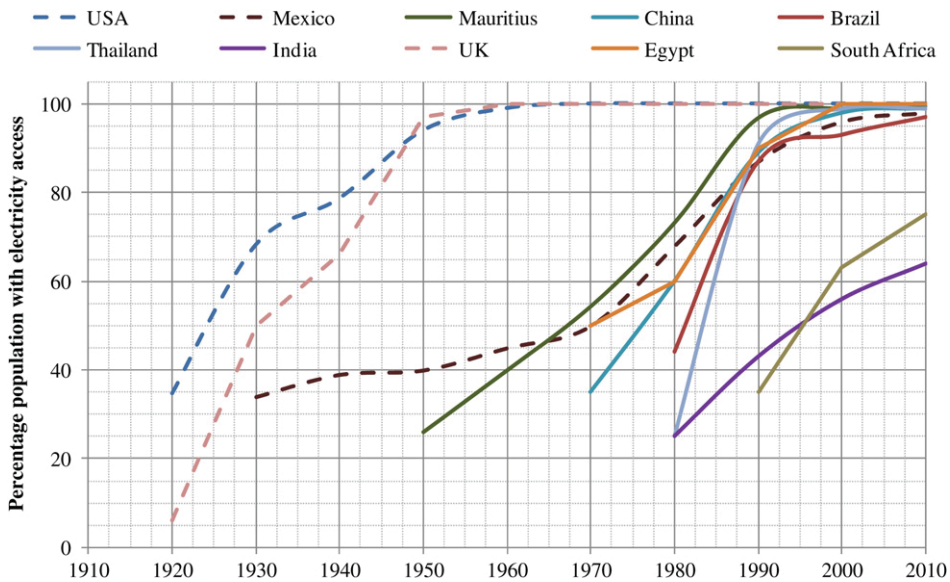

Fig. 2. Evolution of household electrification over time in selected countries (Pachauri et al., 2011).

Fig. 1 shows the total electricity generation capacity installed per million persons (MW/mln) in various regions. It is recognised that this is a relatively rough metric as it does not take into account a number of crucial parameters, including: transmission and distribution (T&D) losses, load patterns, locational constraints, intermittency, temporal reserve, availability, operating efficiency, and outage rates. Compared to other world regions, the ratio of electricity generation capacity per million inhabitants is low in Africa, particularly in sub-Saharan Africa[26]. The figure for Sub-Saharan Africa (excluding RSA) was roughly 129 MW/mln in 2008 only considering people with electricity access; if the entire population is included, the total is about 40 MW/mln.

In terms of electrification of the underserved, history provides compelling evidence that significant increases in the percentages of households with access to electricity can be achieved over relatively short periods of time. As an illustrative example, electrification rose sharply in a number of countries, such as the USA and UK early in the 20th century, and in China, Brazil, and Thailand more recently (see Fig. 2). In the case of Thailand, the percentage of the population with access to electricity went from about 25% to almost 100% in a decade. Still, most countries take at least three decades to make this transition – and most quite a bit longer. In all these countries, electrification, particularly of rural areas, was accorded a high national priority because of economic development or equity objectives.

While several countries in SSA have show dramatic growth (around four-fold) over the last two decades, these mostly started from a relatively small installed capacity. The majority of countries in the region have had sluggish growth, or even a decline in installed capacity[27]. On average, installed electricity capacity in SSA (excluding RSA) grew relatively steadily at around 1.7% per annum. A closer look at the rate of historical growth (or contraction) in African countries (see Fig. 3) is useful for several reasons. First, it illustrates that there is no discernible pattern of any overall increase of the growth rate over time. One might suppose that with growing recognition of the crucial importance of energy, and electricity in particular, efforts to boost generating capacity would have been more pronounced in recent years. This notwithstanding, there are early signs that some acceleration in the expansion of Africa's generation capacity may be taking place. Data on donor commitments to power projects suggest that during the last five years an annual average of 3 GW of generation projects have been committed. Furthermore, the Annual Report of the Infrastructure Consortium for Africa 2010 notes that member commitments to energy projects in Sub-Saharan Africa rose from USD 1.2 billion in 2006 to USD 8.0 billion in 2010.

Second, whilst it shows a very wide range of values[28], the growth rate is generally between 0 and 10%, with the bulk being between 0 and 5%. Third, the variability of the change in installed capacity is high, and is decreasing with time, particularly during recent years. And fourth, the graphical representation indicates that larger systems (depicted as red dots in the Figure) (that is, countries with greater existing capacity and transmission and distribution grids), tend to expand their capacity faster than do countries with medium and small electricity systems. In fact, with few exceptions countries with smaller electricity systems (dots in blue in the graph) have relatively low growth, or even sometimes negative growth, particularly at the end of the 1990s.

Of course, the countries and regions of SSA are acutely aware of energy access issues, both in terms of quantity and quality, and have been developing national targets and regional plans. UNDP and WHO (2009) calculated that 68 developing countries have electricity targets. Brew-Hammond (2010) reviews several sets of ambitious energy access targets as agreed by the regional groupings within the region.

4. Outlook for Africa

4.1. Existing electricity demand projections

In this section, we briefly consider some of the data sets and projections for the power sector in Africa. For an initial sense of scale, using EIA data, Africa has a current installed generating capacity in 2008 of about 122 GW, SSA had 75 GW, and SSA

[26] As illustrative examples of the installed capacity per million of population: Chad and Rwanda: 3 MW/mln; Ethiopia: 10 MW/mln; Cameroon: 54 MW/mln; Ghana: 72 MW/mln; Cape Verde: 150 MW/mln; Namibia: 192 MW/mln; South Africa: 854 MW/mln.

[27] And these are not countries nearing full electrification.

[28] Ranging from −50% to +157%.

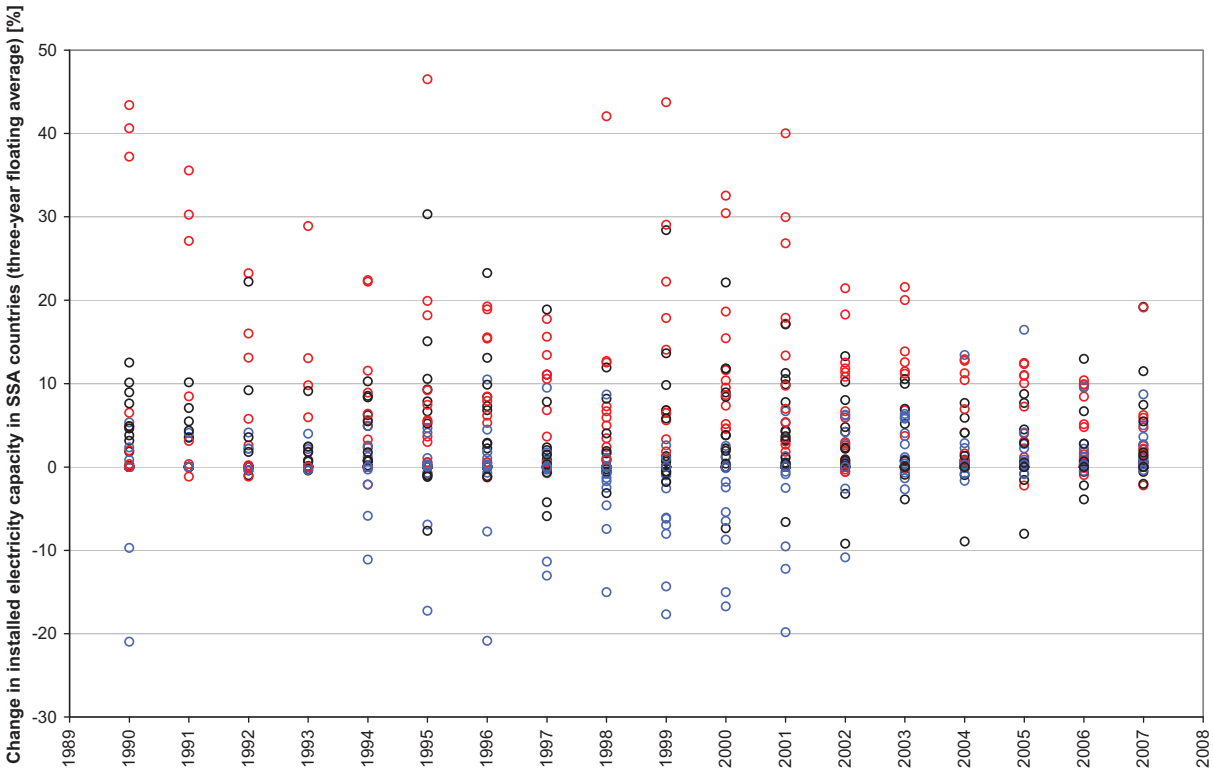

Fig. 3. Rate of increase (or decrease) in installed electricity capacity (with three year floating average) in SSA countries arranged by tertile (red, black and blue dots features countries with relatively large, medium, and small generating capacity, respectively, in 2008). Data: authors' compilation from EIA.

(excluding RSA) had 31 GW[29]. This compares roughly to 28 GW in Argentina in the same year.

Africa is included in the major energy outlooks from the International Energy Agency (IEA), the US Department of Energy's Energy Information Agency (EIA), British Petroleum (BP), and others. Each data set has different levels of descriptive information, coverage, and aggregation[30]. We primarily relied on the EIA data set as it was the most transparent and complete in terms of accessible country time-series data. It is useful to look at results of these high-level global modeling exercises to get a sense of the numbers being fed into the "global energy dialogue".

As an example, the IEA (2010) projects total installed capacity for *all of* Africa at between 270–291 GW in 2030. Depending on one's assumptions about the ratio of SSA and RSA to the African continent, these figures imply approximately 70–80 GW in SSA (without RSA) in 2030.

Most of the African sub-regions have carried out forecasting exercises for peak energy demand[31], commonly both in terms of peak demand (or generation capacity) and consumption (or generation) (See e.g., Nexant, 2004 and 2009). Those projections are normally based on studies conducted at the national level. Despite forecasting methods that vary considerably, the regional plans and related documents entail a wealth of quantitative information that is all too often underutilized in further analysis and planning.

The New Partnership for Africa's Development (NEPAD), Southern African Development Community (SADC), the Forum of Energy Ministers in Africa (FEMA), Economic Community Of West African States (ECOWAS), East African Community (EAC), and the Commission de la Communauté Economique et Monétaire de l'Afrique Centrale (CEMAC), amongst others, have produced strategies for electrification and increasing access to modern fuels.

A closer look at some of the regional forecasts in the interests of comparison is useful. A SAPP electricity demand forecast to 2025 shows a projected annual growth of about 2% (SAPP, 2010); the annual growth rates are projected to be higher outside RSA. Nexant (2004) shows projected WAPP average growth to 2020 of 7.6% (ranging from 5–12.6%). The EAC/EAPP Demand Forecasts (SNC Lavalin, 2010) show very large ranges in forecasted annual growth. They provide very detailed analysis of each country's national forecasts and then extend them to 2038 where appropriate. Interestingly, the forecasts for many of the countries show the same kind of exponential growth we explore in Section 5 in their 'high' scenarios, and reflect more typical trend or regression-based forecasts for "low and base" cases (SNC Lavalin, 2010). Fig. 4 shows, as an example, the forecast to 2038 (in MW) for peak demand in Kenya[32], including showing sharp growth in the "High Case" from 1 GW to over 18 GW to 2038.

Eberhard et al. (2011) develop several scenarios to 2015 for Africa. They considered three types of demand: market, suppressed

[29] Thus, SSA accounts for about 61% of the African continent's total installed electricity capacity (RSA is, in turn, about 59% of the resulting SSA figure). SSA is approximately 1.7% of the world total installed electricity capacity (0.6%, excluding RSA). We use these ratios to derive SSA figures (and SSA excluding RSA) from scenarios that normally treat the African continent as a whole.

[30] These three sources generally are well aligned in their historic data with the EIA figures marginally lower than IEA and BP, likely for reasons of accounting around imports and exports.

[31] To compare to those studies that consider peak demand, a heuristic can be employed by decreasing these figures by 10%.

[32] The MAED model was used for the original demand projections. This relies heavily on GDP growth forecasts – See Section 5 for more on this.

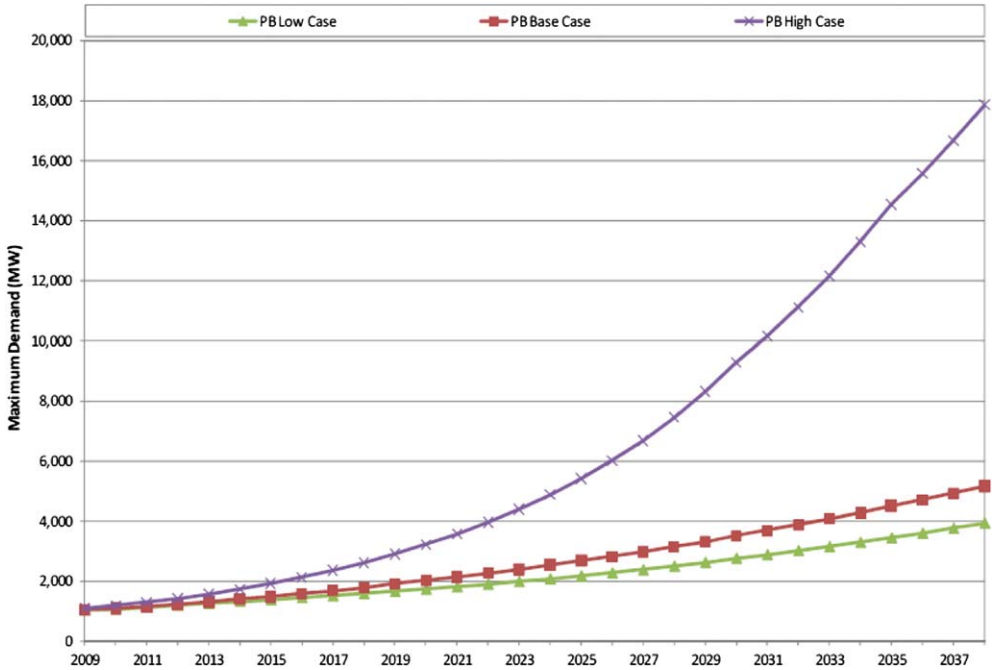

Fig. 4. Peak demand forecasts for Kenya (SNC Lavalin, 2010) to 2038.

and social to help create three scenarios (constant access, regional target and national targets). The overall average annual electricity demand growth rate was estimated at 5.8%.

The objectives of the Study on Programme for Infrastructure Development in Africa (PIDA, 2011), due to be finalized in early 2012, are to enable African decision-makers to, *inter alia*, establish an infrastructure development programme articulated around priorities and phases and, prepare an implementation strategy and process including, in particular, a priority action plan.

The peak demand projections from initial PIDA (for the African continent) shows an average 6.7% growth (with regional annual growth rates ranging from about 6–9%) over the period 2009–2040. The initial results assume that the access rate will increase from 42% in 2009 to 65% in 2030; these rates are projected to be similar in 2040.

The Global Energy Assessment (GEA) developed global energy scenarios that include universal energy access by 2030 as one of the normative objectives (Riahi et al., 2011). As part of this effort, a detailed access modeling within the MESSAGE[33] model framework focuses on the key world regions where the lack of access is currently the most acute, including all of sub-Saharan Africa. The results will be presented both for economy as a whole (Annex 3), as well as a focus on household and rural electrification (see Annex 4).

The African Development Bank (2008) undertook a universal access scenario assessment through 2030. Table 2 shows the results of the capacity additions estimated. Without South Africa the total equals 102 GW – approximately an average of 6% annual growth.

Each of these exercises uses different country coverage, different sector definitions, varying underpinning assumptions, etc. For this reason the figures are difficult to compare and thus, difficult for policy-makers to understand as complementary pieces of information.

[33] Model for Energy Supply Strategy Alternatives and their General Environmental impact (Messner and Strubegger, 1995 and Riahi et al., 2007).

4.2. Generation technology portfolios

In this sub-section, we take a closer look at the various projections in terms of technology and energy resources. We give special attention to renewable energy potentials, following the sustainable energy goal proposed by the United Nations, in order to give a sense of scale to the possibilities.

Eberhard et al. (2011) report that over 900 TWh (approximately 220 GW installed capacity) of economically viable hydropower potential in Africa remains unexploited, located primarily in the Democratic Republic of Congo, Ethiopia, Cameroon, Angola, Madagascar, Gabon, Mozambique, and Nigeria. Similarly, the Intergovernmental Panel on Climate Change (IPCC) estimates the technical hydropower potential at 1174 TWh (or 283 GW of installed capacity), only eight percent of which has been developed. Interestingly, this unused potential is about ten times the current installed generating capacity in SSA if RSA is excluded. Tapping hydropower sources could help greatly in achieving full access as we discuss in Section 5.

The newly formed International Renewable Energy Agency (IRENA) is now designing future renewable energy scenarios. The focus of their work will be on providing detailed, regional specific technology information with a clear focus on renewable energy. Table 3 also indicates that the technical potential for renewables is enormous, and largely untapped, in Africa (IRENA, 2011). The

Table 2
Universal access scenario to 2030 (African Development Bank, 2008).

	Generating capacity [GW]		Total
	Net	Replacement	
Northern Africa: 5 Nations	60	22	82
South Africa	47	30	77
Sub-Saharan Africa: 41 Nations	82.5	19	102
Island states: 6 Nations	2.5	1.5	4
Africa	192	72	265

Table 3
Technical potential for renewable energy in Africa by region (IRENA, 2011). Note: The reference also includes the full sources for each estimate.

Region	Wind [TWh/yr]	Solar [TWh/yr]	Biomass [EJ/yr]	Geothermal [TWh/yr]	Hydro [TWh/yr]
East	2000–3000	30,000	20–74	1–16	578
Central	–	–	49–86	–	1057
North	3000–4000	50,000–60,000	8–15	–	78
South	16	25,000–30,000	3–101	–	26
West	0–7	50,000	2–96	–	105
Total Africa	5000–7000	155,000–110,000	82–372	1–16	1844

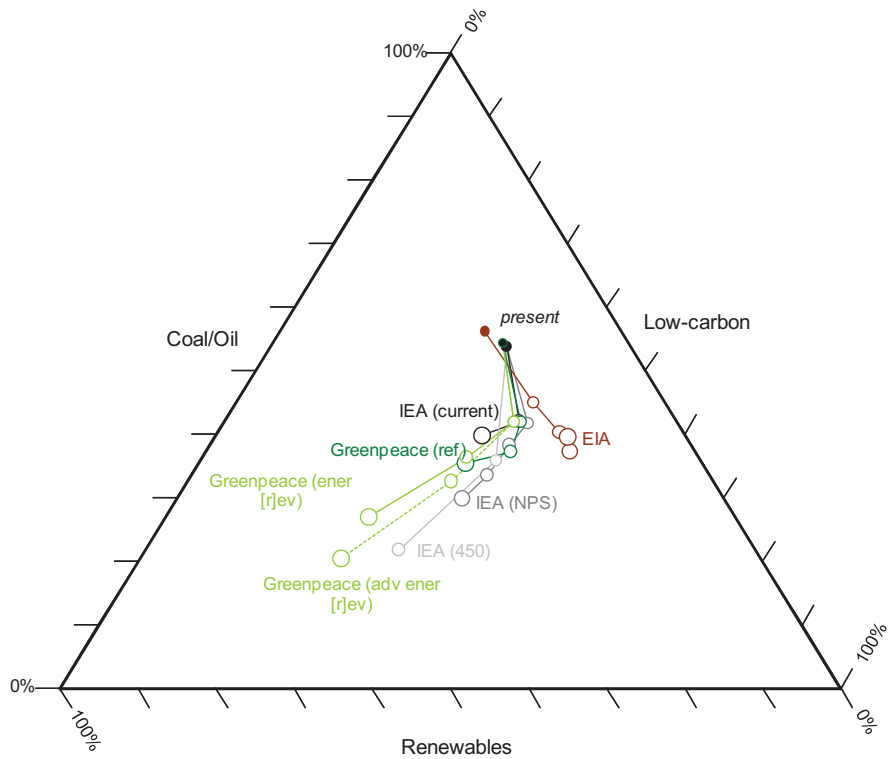

Fig. 5. Various projections of electricity generation in Africa by types of by different organisations, 2010–2030. Note: The size of the dots is proportional to the total electricity generation projected; with present estimates (filled dots), estimates in 2030 (last dot of each scenario), and intermediary estimates. Data: own compilation from IEA WEO 2010, EIA IEO 2010, and Greenpeace 2010.

accounting of biomass remains contentious; still, even using conservative assumptions, the potentials are significant.

In Fig. 5, we use a ternary graph to plot selected (international organisation) projections in terms of electricity production in Africa by types of energy sources, namely coal and oil, renewables, and low-carbon (nuclear and gas)[34]. Such representation allows visualizing the foreseen transition in the electricity generation and corresponding technological and resources shift. The portfolio of generation types critically impacts power system design and operation (including the amount of total installed capacity required because of issues such as intermittency, ramping rates, and inertial response). All of the projections foresee a decrease, in relative terms, of carbon-intensive resources in Africa in the coming two decades, including those scenarios without an explicit focus on climate change mitigation. Also, most projections feature an increase in low-carbon technologies in a first phase, before the share of renewables picks up significantly[35].

[34] The data of the GEA could not be directly compared because of the different regional definition; further details are provided in Annex 3. In addition to international organisation projections there are, of course, sub-regional and national scenarios that consider different generation portfolios (see e.g., Nexant, 2009).

[35] It is interesting to note that the EIA projection contrasts with the others in that the share of renewables remains stable or decreasing over time; only the share of low-carbon options increases. EIA's renewable electricity projections are based on the expected value of the current policies – the stated target (either capacity or generation) multiplied by an assumed probability of achieving that target. Comparing the EIA to IEA's WEO 2010, it appears that EIA's hydroelectric projected growth rate is similar to IEA's while wind, solar, geothermal, and biomass growths rates are much lower. IEA seems more optimistic about non-hydroelectric renewables deployment than EIA. EIA assigns low probabilities to non-hydro renewable projects and policies in Africa because of the lack of historical support for these options. Hydroelectric power plants, however, have been successfully built in Africa for many years.

Table 4
Estimates for installed electricity generation capacity required (in GW) in SSA (excluding RSA) under various access level (MW/mln) assumptions.

Level of access	2010 [GW]	2030 [GW]	Implied average annual growth rate 2010–2030	Scenario name
Population - electricity poor, million	573	638	0.5%	
Population - non electricity-poor, million	240	615	4.8%	
Electricity poor: 0 MW/mln non electricity-poor: 129 MW/mln[38]	31	79	4.8%	*Business As Usual*
Electricity poor: 200 MW/mln non electricity-poor: 400 MW/mln		374	13.3%	*Moderate Access*
Full population: 400 MW/mln		501	14.9%	*Full Access*
Full population: 800 MW/mln		1002	19.0%	*Full Enhanced Access*

5. Simple scenarios to 2030

5.1. Scenarios

Using simple heuristics, we calculate electricity generation capacity required in SSA (excluding RSA) to 2030 under various electricity access level assumptions (see Table 4). It is important to note that these scenarios are not limited to household demand, but for the entire economy. In the first two scenarios we separate the number of people without access (electricity poor) from those with access (non electricity-poor)[36], and each category arrives at a different level of access in 2030. In the two other scenarios the entire 2030 population is brought to a single average level of access. Of course, such results are highly stylized and would, in themselves, not properly consider issues such as: intermittency of various energy sources, load factors, reliability, availability, interconnection, system operation, ramping, etc. (We employ a different, yet equally transparent, methodology in Annex 1, which provides a similar scale of result.)

The results of this exercise are astonishing in terms of the required growth rates and installed capacity. As an example, just to reach the our *Moderate Access* case where the population has between 200–400 MW/mln requires a total of around 374 GW of installed capacity – about twelve times current levels. This implies around a 13% annual growth rate for the next 20 years as compared to 1.7% for the past 20 years. The other scenarios show that bringing access to the projected SSA (excluding RSA) population in 2030 would take approximately 500 GW to reach an average of 400 MW/mln (*Full Access)* and to reach 800 MW/mln (the current rate of RSA – *Full Enhanced Access*) would double this requirement. We recognise that our results assume much higher levels of access than much of the literature that focuses solely on "basic needs" at the household level[37]. Annexes 4 and 5 briefly explore elements of such a scenario.

Fig. 6 provides a simplified overview of several scenarios as well as projections. In addition to plotting the *Moderate Access* and *Full Access* scenarios from Table 4, it includes: a *50% Access* scenario that assumes that 50% of the population will have access at a rate of 400 MW/mln, along with two statistically derived projections based on historical data. *GDP regression* represents a regression analysis using GDP[39] as the independent variable (with double exponential smoothing of historic data), and results in about 70 GW in 2030[40]. The *Trendline* is a historically-based extrapolation, and projects about 43 GW in 2030. We portray the scenario curves as having exponential growth, but of course growth in power capacity will likely be much more "lumpy" and unevenly distributed.

It is also useful to consider how to "jump-start" from historic trends to, as an example, the *Low Access* case. A few well-designed large projects would allow very high initial growth levels to help give confidence to the sector for an extended period of growth. For instance, the proposed Grand Inga hydroelectric project (in the Democratic Republic of Congo) could reach almost 40 GW in scale. Inga then would, theoretically[41], provide a significant short-term contribution to the additional capacity required. Likewise, some Nigerian projections show very high levels of short-term growth in generating plants (Gujba et al., 2011)[42]. A few such large-scale projects might also provide the necessary impetus for transmission projects. High levels of growth in smaller or distributed generation projects would also likely support the necessary momentum.

Finally, while it is valuable to illustrate what it would mean to meet a target of 100% electrification by 2030, it is also important to acknowledge that this target seems ambitious. As noted above, 30–40 years may be a more realistic range based on the historical evidence, particularly given the following considerations:

- The final segment from 90%–100% access is necessarily slower due to increasing marginal costs and technical difficulties, as Fig. 2 bears out.
- In addition, historical precedent, as reported in Fig. 2, describes single country achievements; whereas for Africa to meet the universal electrification target 47 countries would need to do simultaneously.

5.2. A closer look at the sub-regions

Building on our *Full Access* scenario (See Table 4), we briefly examine this goal 'spread' evenly across the sub-regional power pool level (the Eastern Africa Power Pool (EAPP), Southern Africa Power Pool (SAPP), Western Africa Power Pool (WAPP), and the Central African Power Pool (CAPP)). In the process, we developed a simple capacity expansion model (See Annex 2)[43].

Initial results show that the WAPP has the largest total capacity additions at 186 GW, the EAPP has 149 GW, the SAPP (excluding RSA) has 105 GW, and the CAPP has 27 GW (see Fig. 7)[44]. On an average annual basis then, SSA (excluding RSA) must add about 23 GW per year in additional capacity (EAPP: 7.4 GW, SAPP (exluding RSA): 5.2 GW, WAPP: 9.3 GW, and CAPP: 1.4 GW) –

[36] Population growth forecasts are taken from World Population Prospects: The 2008 Revision, United Nations Population Division, UNDATA; *medium variant* scenario. We use the electrification rate forecast from the IEA (NPS) scenario which leads to 640 million without access in 2030.

[37] Thus the term 'moderate' in our scenario.

[38] Maintaining current levels with population growth.

[39] GDP forecasts (in current prices) are taken from the World Economic Outlook database.

[40] For comparison, if the IEA (NPS) figures from the IEA 2010 WEO were first decreased by the 2008 ratio of SSA to Africa (61%), then decreased by the historical rate for SSA (excluding RSA) to SSA (41%), then increased that ratio up to 49% in 2030 and finally decreased by 15% to allow them to be comparable to EIA data; that number would be 71 GW.

[41] Again, of course issues of transmission and the like would make this thought exercise highly abstracted. Recent reviews from the World Bank suggest about 30 GW of large hydro projects in the SSA region are feasible in the next 10 years.

[42] The scenario shows around 10 GW of hydro coming on line to 2030, and about 7 GW of expansion in all technologies to 2020 in Nigeria alone.

[43] EAPP: capacity and generation data and reference growth rates from SNC LAVALIN 2011; SAPP: capacity and generation data and reference growth rates from SAPP 2009; WAPP and CAPP: capacity and generation data from EIA.

[44] Just for the sake of clarity, these numbers equal approximately 470 GW (501-31 GW from Table 4).

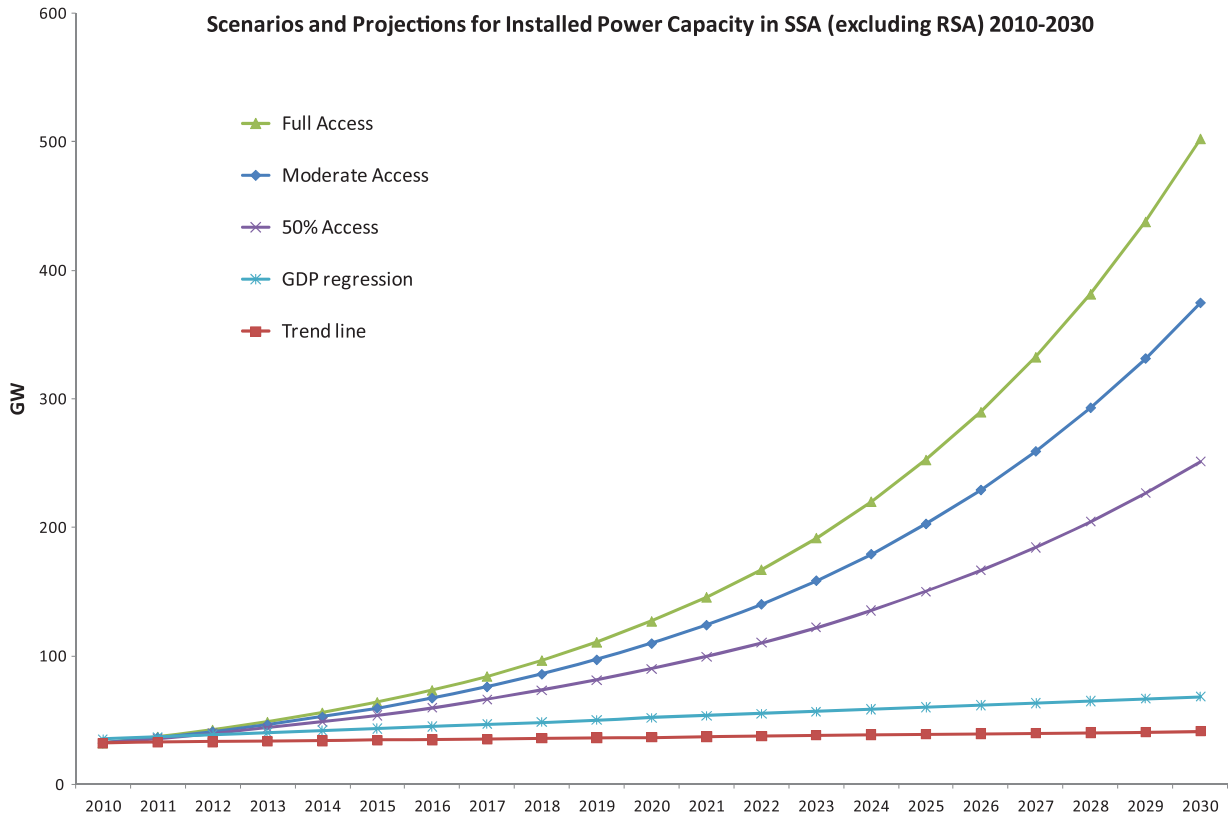

Fig. 6. Scenarios and projections of installed electricity capacity to 2030 for SSA (excluding RSA).

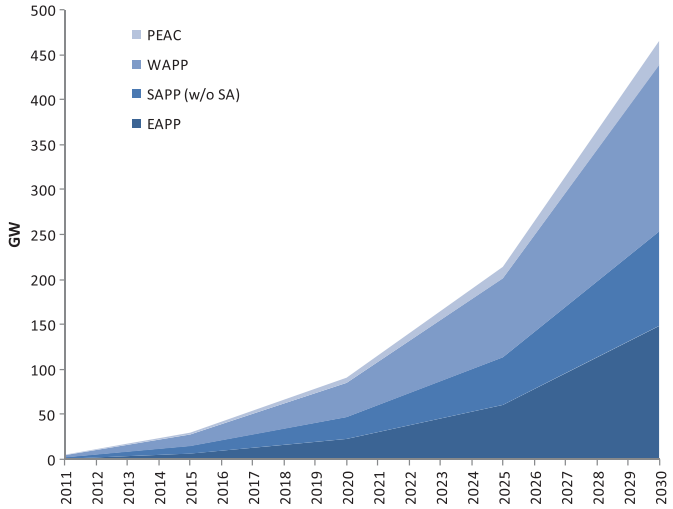

Fig. 7. Additional capacity needed to reach 400 MW/mln by region.

equivalent to a little more than a Three Gorges Dam (22.5 GW) sized project each and every year through 2030.

Using our regional model, we also explored cost implications of the universal energy scenario. The results are presented in Annex 2, so as not to distract from our focus on generation capacity.

6. Conclusions

Almost every country in SSA has produced forecasts and a roadmap (some with explicit targets for access) for their power sectors - building on these is essential. To that end, and to give a high-level perspective for the benefit of the international community, we have outlined several simple, transparent scenarios for the power sector in sub-Saharan Africa. They employ a highly simplified methodology to provide a sense of scale of the growth challenges inherent in working towards universal access to electricity services. Still, it is recognised that 'bankable' policy and investment decisions necessitate more detailed and complex analysis and planning down to the level of individual power plants and related transmission and distribution infrastructure. Thus, there is still room for further, more detailed analysis.

Despite a host of information regarding obstacles to universal access to energy services, and various proposals for financial, regulatory and other tools to address them, understanding the immense scale of the endeavour is necessary to provide a context for, and help guide policy-making. The exercise also provided some clarity on several key analytical assumptions that drive power system planning, such as growth rates and mid-term access goals.

Most projections from international organizations, regional entities, national governments, and power companies foresee average annual growth rates in generating capacity on the order of 6–8% – in line with GDP forecasts – and typical demand forecasting techniques. While these are dramatic increases over historical rates, and would result in installed capacities of about three-times current levels in just two decades, they are insufficient to meet even modest definitions of universal access. Our scenarios demonstrate the need for at least ten times more installed capacity than today by 2030 (implying sustained average annual growth rates of around 13%). Some kind of "jump-start" is likely required to move the growth pathway onto this new trajectory – this will entail a mix of both large-scale projects, as well as a host of distributed generation, the integration of large amounts of renewable energy, and new ways to conceive of power system planning (including Smart Grids).

The role of the international community is best employed to help encourage the cooperative movement of the disparate pieces towards a common goal, and to supply the necessary technical and investment tools. As an example, a reliable and comprehensive information base is required to set targets and monitor outcomes, to design strategies and policies, to make evidence-based decisions, and to enable consumers to make informed choices. Providing access to energy services is a concrete problem, with clearly discernible benefits; this, along with its current political prioritization offers ample opportunity for international efforts.

Acknowledgements

We would like to thank a number of colleagues for their support: Solomon Abebe (UCB), Vijay Iyer (WB), Keywan Riahi and Yu Nagai (IIASA), Brian Murphy (EIA), Jacques Moulot (AfDB), Dolf Gielen (IRENA), Kandeh Yumkella and Alois Mhlanga (UNIDO), Charlie Heaps (SEI), Padraig McManus and John Shine (ESB), and Reid Detchon (UNF).

Annex 1. An energy consumption-based calculation for universal energy access

We also explored an alternative, and equally transparent, approach to project forward generation capacity requirements for SSA (excluding South Africa) for the period out to 2030. The methodology takes as a starting point the 2008 electricity consumption levels in that region of 155 kWh[45] per capita. We then assume that with full access, electricity demand will grow by 2030 to consumption levels achieved in other regions where full access already exists. Specifically we assume that 2008 electricity consumption levels in Northern Africa (1285 kWh per capita[46]) will be achieved by SSA (excluding South Africa) by the year 2030. This consumption level is clearly significantly higher than current levels, but remains considerably lower than levels elsewhere and is thus considered a reasonable first estimate.

Combining this 1285 kWh per capita assumption with population projections allows us to calculate annual electricity demand in 2030 for SSA (excluding South Africa). We used two UN population scenarios, namely *medium variant* and *constant fertility scenario*[47] and the resulting electricity demand grows from 119 TWh in 2008 to 1390 and 1593 TWh by 2030 respectively for each population growth scenario.

The electricity generation capacity required to meet this demand is dependent on the average annual electricity system load factor. The load factor over the period 1990–2008 for SSA (excluding South Africa) has varied from 31% to 47%[48]. In this analysis it is assumed that the load factor will increase to 50% by 2015 and remain at that level until 2030. The reason for using 50% is that it represents the average load factor for North Africa for the period 2000–2008.

Using this approach, the electricity capacity increases from 31 GW in 2008 to roughly 317 GW (medium variant) or 364 GW (constant fertility) in 2030 – well aligned with the results from Table 4. It is also worth noting, these projections for 2030 are between 4.2 and 4.8 times higher than the IEA NPS (WEO, 2010) projections for the region.

Annex 2. Regional costs

In addition to the description of the model (and results) in the main text, we present some cost estimates in this Annex. The model begins with a generic load duration curve (LDC) with a shape derived from LDCs presented in SNC Lavalin (2010). The generic LDC is then fitted to each region's capacity and generation output so that it matches the region's overall capacity factor. The model uses LDCs to determine the least-cost mix of new baseload and peaking capacity to meet electricity demand growth. Based on regional projections for new capacity (e.g., hydro, gas or coal) in Eberhard et al. (2011) we defined a baseload technology for each region using cost and performance characteristics from EIA (2011).

Transmission and distribution (T&D) investments are critical for any expanding electricity system, but particularly for systems that are expanding to meet universal access goals. We developed a simple heuristic based on forecasts from Eberhard et al. (2011) for the necessary T&D investments per MW of new capacity for each region, and applied the factors to our regional projections of capacity. As 2030 approaches, though, the T&D infrastructure needs will likely begin to lessen as the networks become more extensive; therefore, we assume that the T&D factors for each region will linearly decline 25% by 2030, subject to a minimum factor based on South Africa's T&D requirements.

For all of SSA (excluding RSA), the total investment cost (generation capacity plus T&D) of reaching the 400 MW/mln universal access goal is roughly USD 740 billion NPV (5% discount rate). Operating costs add another $130 billion NPV. The average annual investment in generating capacity is thus USD 49 billion and in T&D is USD 24 billion. The WAPP has the highest average annual investment requirements at USD 21 billion, and the CAPP has the lowest at USD 3 billion (see Fig. A2.1). These figures are far higher than those normally found in the literature (i.e., IEA, 2010). For a review of investment costs see Bazilian et al. (2010c).

This universal access scenario for SSA results in regional costs per MWh that are largely consistent with those reported by Eberhard et al. (2011) (which reflect the period 2005 to 2015). We find that the levelised costs for SAPP (excluding RSA), South Africa,

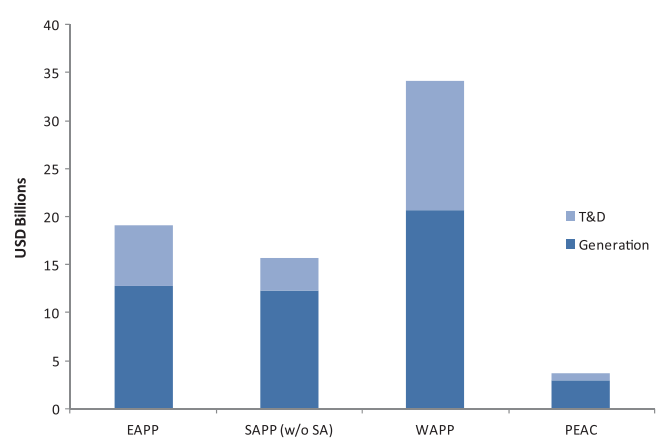

Fig. A2.1. Average annual investment needed to reach 400 MW/mln by region.

[45] We use IEA 2010 Key Energy Statistics Report to calculate electricity consumption in Sub-Saharan Africa (without South Africa) as 119 TWh and combine it with the 2008 population of 772 million.

[46] Using data from IEA (2011). The range in electricity consumption in Northern Africa in 2008 was considerable, varying from 744 kWh per capita in Morocco to 3,920 kWh in Libya (with high electricity intensive energy industry activity linked to the oil sector).

[47] The medium variant scenario results in 12% per annum growth in electricity demand over the period 2008 - 2030. This is twice the growth rates in North Africa (5% per annum on average) over the previous 20 years but not significantly higher than growth there in the past ten years (7% per annum).

[48] Based on EIA data. The load factor in Sub-Saharan Africa has increased from 43% in 1990 to 55% in 2008. When South Africa data is excluded, the load factor varied from 31% to 47% over this period.

and CAPP are all below $100/MWh. The levelised cost for EAPP is $116/MWh and for WAPP is at a rather high $166/MWh. The third column is the levelised cost over the period to 2030 (Fig. A2.2).

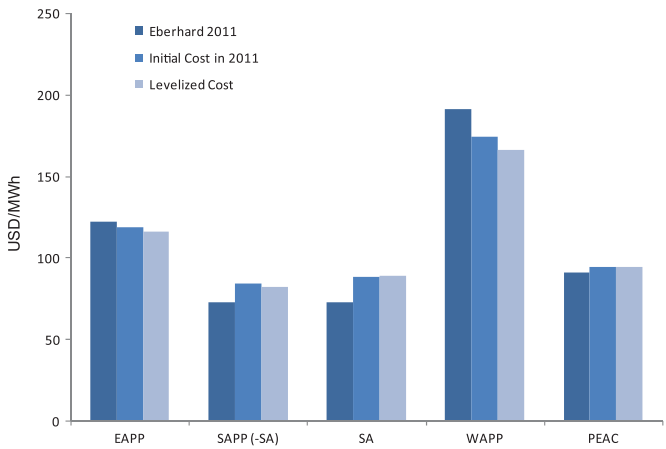

Fig. A2.2. Comparison of the full cost per MWh in our universal access scenario to costs reported in Eberhard et al. (2011). Note that our costs include annualized capital investments in generating capacity and T&D, as well as fixed and variable operating costs.

Annex 3. Global energy assessment economy-wide access scenarios

We present in this Annex, several scenarios for economy-wide universal access to electricity for all of SSA (Riahi et al., 2011). Fig. A3.1 shows baseline and universal access cases under two different climate scenarios – with and without climate policy – and the resultant generation technology portfolios. These figures assume fairly low-levels of access to electricity, and include RSA, so they are difficult to compare to our results. The GEA model runs in regions, and thus it is difficult to remove one country from the assessment. Still, under certain assumptions one can assume that if we subtracted RSA from these figures, that they would lie somewhere between our *GDP regression* forecasts, and our *Moderate Access* scenario.

Annex 4. Global energy assessment scenario for basic services to the household sector

For the purposes of quantification, two alternative levels of demand are assumed as the minimum required for ensuring access at the household level. These correspond to two different electricity service levels[49]. The MESSAGE–ACCESS model defines electrification in terms of the basic minimum required to meet household needs. Future rates of electrification in the model are driven by future income growth. Fig. A4.1 shows rates of access in the base year and projections to 2030 for a scenario with no new policies or resources for improving the rate of electrification, and another with a universal rural electricity access target. In sub-Saharan Africa, rural electrification in 2005 was less than 10%. Following a trend with increasing GDP per capita, in the no new policies scenario, this is projected to increase to only 15% according to the analysis based on the MESSAGE-ACCESS model by 2030[50]. It was estimated that the additional generation capacity required by 2030 to achieve universal rural electrification in sub-Saharan Africa is between 14 and 20 GW[51].

Annex 5. OSeMOSYS scenario for basic services to the household sector

We explored another "basic household energy services" scenario using the free and open-source OSeMOSYS[52] tool to develop an assessment of the extra capacity requirements for providing access to (all of) SSA by 2030. It was primarily based on, and extends aspects of (WB, 2011) as well as other sources[53]. In order to determine the minimum costs required to undertake the electrification, a scenario was run to investigate reaching universal access in Sub-Saharan Africa where only low volumes of electricity to be used by newly electrified homes[54].This is useful as it helps to indicate minimum expenditure levels on the one hand. On the other, should development occur faster, higher costs incurred may conceivably be covered by extra income generated during associated economic growth. Starting with the existing energy system, the effort assumes that most grid connections would take place in urban centers, while off-grid connections would be outside those centers.

Essentially at the "peaky" household usage patterns expected[55]: low capital cost, high running cost power system investments are often most economic to meet new demand. Levelised (IEA, 2010) with a 10% discount rate, four household access options are indicated by Fig. A5.1. Note that when grid connection is expensive, providing electricity to remote homes can be cheaply achieved with diesel generators – a common practice in SSA (Howells et al., 2005). In other instances, when the diesel price is high (often due to significant transport charges), photovoltaic (PV) solar home systems (SHSs) are competitive. In particular, this occurs in remote rural areas[56]. In this analysis it is assumed that 50% of the time this was the case for off-grid connections - and PV SHS systems were thus chosen by the model[57].

To reach a target of basic household-level universal access, about 5.9 and 2.5 rural and urban houses require connecting annually. To do so, around USD 3.4 billion would be spend annually for off-grid efforts, and USD 4.4 billion for grid-based connections.

[49] 1.) A minimal access case: each household has one conventional light bulb (40 W), and one out of three households has a television set (60 W); on the assumption that these are used for 3 hours a day, this amounts to approximately 65 kWh per household per year. 2.) A sustainable universal access case: consumption is assumed to be 250 W for 4 hours per day for lighting, and other applications as in the Tanzanian reference study of Modi et al. (2005), amounting to 420 kWh per household per year.

[50] For details regarding core assumptions of GDP and population growth in the GEA-M scenario used as the base for the universal access scenario analysis see (Riahi et al., 2011).

[51] Again, this aspect of the GEA exercise focused only on household demand, unlike the rest of this paper, which considers the full economy.

[52] The OSeMOSYS model is open source and freely available and can be accessed from www.osemosys.org. (See also: Howells et al. in press.

[53] Additional load curve data were estimated from Lloyd et al. (2004) and Howells et al. (2006) and cost data from (IEA, 2010a). Technology choices were based on minimizing total life cycle costs (see Howells et al., in press). Based on a UN BAU projection of 1.5 billion living on the continent with a 50-50 urban-rural split (UNDESA, 2009), assuming current electrification proportions (IEA, 2011), and 5 people per home approximately 47 million urban and 113 million rural homes need electrifying.

[54] A meager 100 kWh per month in an urban home, and 20 kWh per month in a rural home (Kaufman, 2000 and Bazilian et al., 2010a).

[55] A load factor of around 25% was assumed based on Lloyd et al. (2004).

[56] Above USD1.6/l in this analysis. Note that the crude oil price was assumed to be at USD 70/bbl, with other fuels costed (on an energy basis) relative to that. Salient for the calculations reported here: HFO was 85% of the crude price, diesel for bulk generation twice that, and for distributed generation three times that.

[57] Note that many other off-grid options were not considered in this analysis due to the deliberately transparent and meta-nature of the thought experiment. However future work should account for several shortcomings of this, including the rich variety of options available in a continent as heterogeneous as Africa.

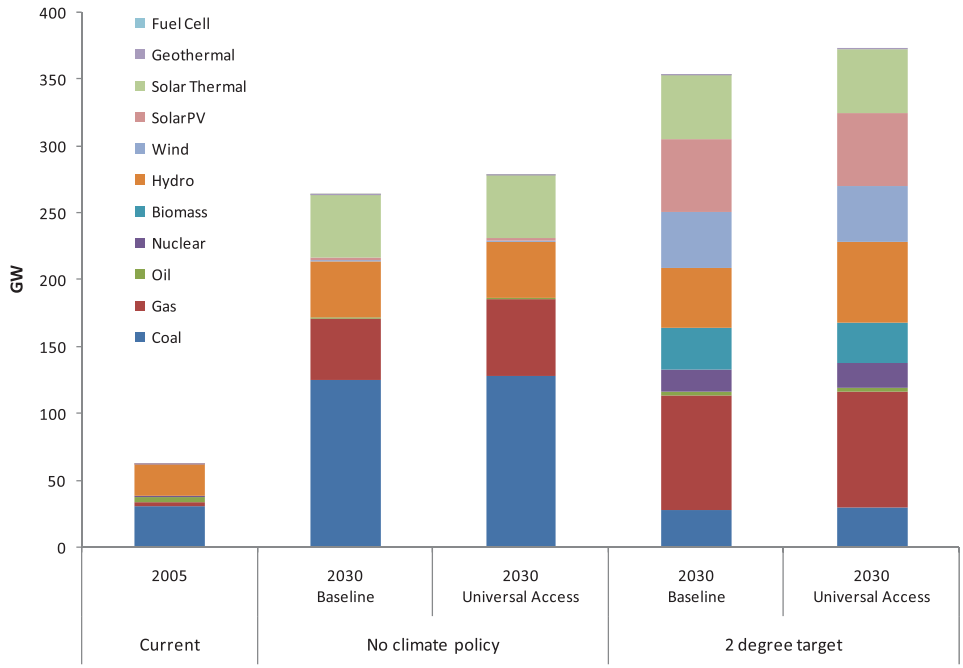

Fig. A3.1. GEA scenarios with resultant generation types to 2030 (Riahi et al., 2011).

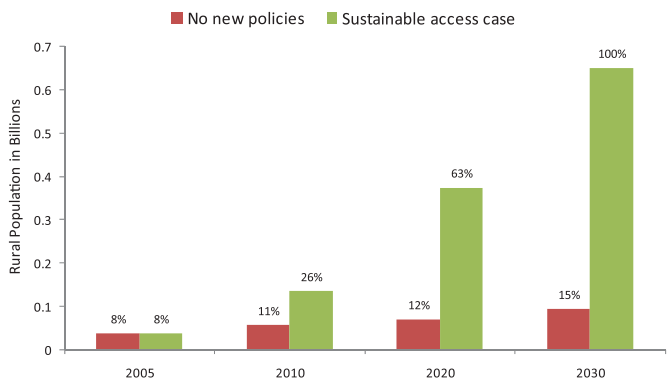

Fig. A4.1. Access rates for two scenarios (IIASA, 2011).

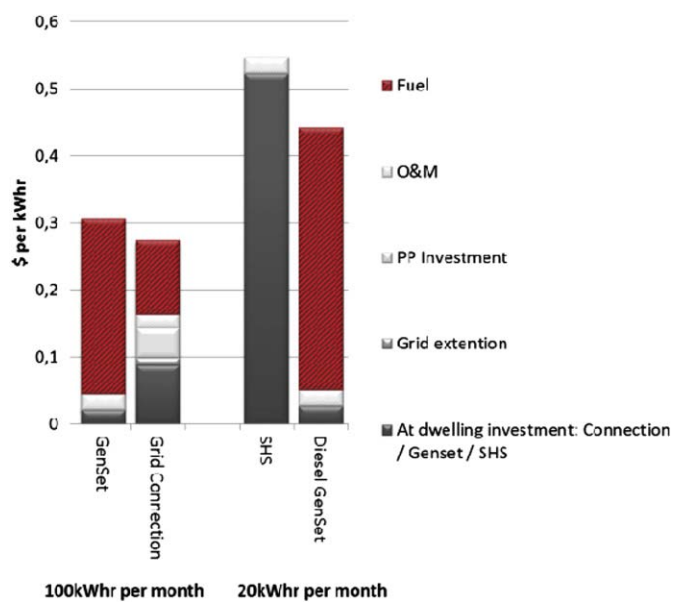

Fig. A5.1. Levelised costs of providing electricity to newly electrified low-volume consumers.

The relative cost splits are given in constant terms by Fig. A5.2. Off-grid expenditures and connections are indicated above the X-axis (and on-grid, below). The costs decrease over time as they are discounted. As the PV SHS's are assumed to last for 10 years, annual investment costs double in real terms in 2026 as initial investments made from 2012 on need replacing. Note that while the on-grid connections decrease in constant terms, they do so slowly. This is because each year the fuel bill increases, as (unlike the PV off-grid systems) each new connection implies more electricity needs generating - and that from fossil (based heavy fuel oil (HFO)) sources. So each year that bill cumulates[58].

To meet these targets approximately 12 GW of off-grid SHS's and diesel gen-sets would be deployed. While on-grid, at least 30 GW of low-cost, low load-factor oil based plants would be added. Interestingly, these are all investments that carry a low risk to the investor. The technologies are mature, available 'off the shelf' and require low lead times for their deployment. With the positive message that this task is not insurmountable, next steps require a far more nuanced analysis. This would involve correctly assessing the trade-offs between grid and off-grid options, the role of smart grids to help organically integrate growing micro, mini, national and regional grids. And, within this context how best to unlock Africa's vast renewable and other potential, to make environmentally compatible sources to fuel a growing continent, while not forgetting the urgency of the task.

[58] Note that on-grid connection costing here includes: 1.the cost of the household connection, 2.costs of extending the transmission system, 3.costs for new grid based power plant construction (accounting for an assumed 20% system losses) as well as annual operating and fuel costs. Note also that on-grid connections are significantly more expensive than off grid connections, as higher volumes of cheaper electricity are assumed to be consumed.

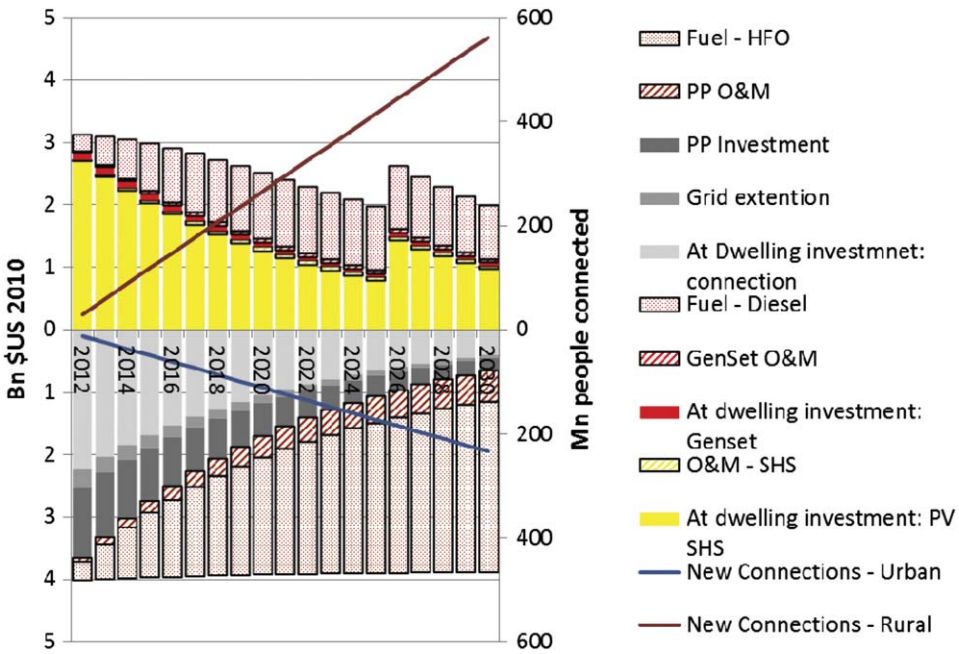

Fig. A5.2. Minimum annual costs associated with global electrification.

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