Modelling the Urban Energy Future of Sub-Saharan Africa – Exploring Strategies for Sustainability

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Abstract

This paper explores the results of a modelling exercise undertaken to assess the future urban energy demand of Sub-Saharan Africa. An energy systems model was developed drawing on the recently improving data picture for Sub-Saharan Africa on electricity use and access, rates of urbanization, biomass use and influence on carbon flux and typical urban energy profiles. Initial results indicate that the demand for energy could double by 2025 and grow fourfold by 2040, with CO_2 emissions rising 280% by 2040, shifting the region's share of global emissions from 1% to 4%. Strategies for improving urban sustainability are assessed quantitatively and critically compared; access to modern energy could for instance reduce CO_2 emissions by around 17%. Survey work shows suppressed demand to be high and so energy efficiency measures may however be offset by the demand that access to modern energy unlocks.

The results suggest that urban areas have a key role to play in the energy future of sub-Saharan Africa, and may be an increasingly important global energy player. Understanding the state of energy in cities – where energy is being used, how this is likely to change over time, and locally appropriate sustainability measures – is likely to be an important part in shaping a prosperous future for sub-Saharan Africa and implementing global intentions around the SE4All[1] and energy-related Sustainable Development Goals.

Keywords
City, Energy, CO_2 Emissions, Strategies, Modelling, Sustainable Development, Sub-Saharan Africa

[1] Sustainable Energy for All – A United Nations and World Bank partnership which aims to support the attainment of Sustainable Development Goal (SDG) 7 which calls for access to affordable, reliable, sustainable and modern energy for all by 2030

1. Introduction

Global energy demand is continuing to grow and much of this growth is in urban areas with over 50% of the world's population currently living in urban areas and accounting for approximately 80% of world GDP and two thirds of primary energy demand and energy related CO2 emissions (IEA, 2016). As these urban populations continue to grow, there will be a large impact on global energy demand and the resultant carbon emissions (GEA, 2012). Sub-Saharan Africa is currently home to 13% of the world's population but is only responsible for 4% of its energy demand – and much of this demand is met from traditional biomass fuels (IEA, 2014). Given Sub-Saharan Africa's (SSA) relatively low energy demand per capita, and the fact that much of it is from biomass the region is typically considered a relatively small contributor to future global energy demand and carbon emissions (IEA 2014).

Much of Africa is still early in its development trajectory and population growth is projected to be high, especially in sub-Saharan Africa. Much of this growth is set to occur in urban areas, often in very dominant capital cities (UN-HABITAT, 2014). It is therefore key to develop an understanding of evolving energy demand in specifically urban areas and how this relates to energy demand in the sub-continent and globally. The low base of most economies in the region, growing populations and potentially large commodity resources raise the possibility of a rapid increase in its share of global energy demand and emissions in the context of general pessimism regarding limiting global average temperature increase to 2°C. Furthermore, a shift of urban growth to secondary or satellite cities is becoming evident, raising the concern that weak local government and energy access problems will lock a large segment of development into inefficient, ineffective and unsustainable energy technologies and fuels (UN-HABITAT, 2014). National energy policies in sub-Saharan Africa often focus on rural areas and the energy supply sub-sector. Yet with the population growth in urban areas, and resulting national energy profile changes, the emphasis is needed on the urban energy futures of African countries.

A regional energy systems modelling and greenhouse gas emissions assessment literature is emerging in response to the twin challenges of energy access and climate change and also enabled by an improving data picture. Electricity supply in particular has been modelled and analyzed in detail from the perspective of the costs of greatly improved or universal access with a more sustainable and regionally integrated power system (Rosnes & Vennemo, 2012), (Taliotis, et al., 2016). The cost benefits of regional trade in electricity particularly from renewable sources, chiefly hydropower, comes out strongly in these studies and at least one model, TEMBA, is public. A more spatially detailed and specific approach has been implemented by (Mentis, et al., 2015) which applied GIS data across large regions to assess the lowest cost option, whether grid connection, mini-grid or stand alone systems, for providing electricity access to each area subdivision in the study region. This is based on a liveliest cost of electricity calculation accounting for local population density, proximity to the grid and scenarios of per capita demand and fuel cost. The model has been implemented in a public interactive on-line tool (UN-DESA, accessed 2016) for the whole of Africa. A number of rigorous assessments of the future options for the power sector in sub-Saharan Africa and the base data for detailed electricity supply modelling are therefore available in the public domain.

Much research effort has been directed at determining a full greenhouse gas budget for Africa including regional assessments for sub-Saharan Africa (SSA) (Valentini & et al, 2014) (Bombelli & et al, 2009) (Ciais & et al, 2011). The relatively low per capita fossil fuel emissions in SSA coupled with still heavy forest coverage make it likely, but not certain, that the region is still a net sink although land use change and forestry (LUCF) emissions are high at around 4-fold total anthropogenic CO_2 equivalent emissions in 2008 (Bombelli & et al, 2009). These are rising due to deforestation and forest degradation for cropland clearing, industrial wood harvesting and fuelwood collection, outcomes which in SSA have tended to be permanent making the region now a major contributor to deforestation (Ciais & et al, 2011). Fuelwood harvesting is not thought to currently have a significant effect on carbon flux on a decadal timescale through land use change but is a significant (+/-36%) share of biomass consumed by woodland and savannah burning (domestic burning included with these by convention) . Emissions from fires in Africa are now estimated to account for 52% of global carbon emissions by fires and 36% of CH_4 emissions caused by fires (Valentini & et al, 2014). Sub-Saharan African cities, due to low electricity access rates, high costs and poor quality of supply still account for a substantial and growing demand for fuelwood and charcoal with demand for fuelwood having grown in the region by 1.7% year on year and charcoal by 3.8% year on year between 2004 and 2014 (FAOSTAT, accessed April 2016). Continued compound growth in the energy system as it is now, could see fuelwood become a serious source of GHG emissions and a more damaging component of deforestation adding to the already severe pressures brought to bear by agricultural practice in addition to the impacts on human health arising from smoke inhalation.

There is a clear rationale, building on the foundation provided by the above research and the improved public data being made available by development agencies, to undertake complementary modelling and policy support work that has an urban focus particularly on less resourced secondary cities. This direction is consistent both with Sustainable Development Goal 11, "Sustainable Cities and Communities" and with the International Panel on Climate Change's clear indication in their 5th assessment report that action at a devolved city level is essential to mitigate and adapt to climate change (UNDP, 2016) (Revi, et al., 2014). The work undertaken for this paper is part of such an initiative, the "Supporting African Municipalities in Sustainable Energy Transitions" (SAMSET) project that seeks to build capacity and develop a practical and effective knowledge exchange framework for supporting actors involved with municipal energy planning. SAMSET is a collaboration between the Universities of Uganda Martyrs, Ghana, Cape Town, Durham and University College London, the non-profit organization Sustainable Energy Africa (SEA) and UK based Gamos Consulting (SAMSET, 2016) (Bawakyillenuo, et al., 2015). The development of energy models and datasets is a key aspect of this programme including the development, initially, of 2 municipal scale energy system models in each of the African partner countries, Ghana, South Africa and Uganda. These involved primary data collection by the local institutions in collaboration with the respective municipalities which has been used as partial input to an energy systems model of the aggregated urban areas of the region, the sub-Saharan African Urban Energy Futures Model (UEFM) the focus of this paper. UEFM has been developed on a common platform with the six current city models developed for the SAMSET project, the Stockholm Environment Institute's (SEI) Long range Energy Alternatives Planning System (LEAP) platform. LEAP is a bottom-up accounting type simulation model but enables power system least cost optimization through a link to OseMosys and is widely used, particularly for national climate change strategy reporting to the IPCC (Bhattacharyya & Timilsina, 2010). The rationale for the selection of LEAP as a tool for the SAMSET project has been documented in another project output (Tait, McCall, & Stone, 2014) and the LEAP software tool itself is well documented by SEI (http://www.energycommunity.org).This goals of the UEFM research are as follows:

- Develop an energy systems model disaggregated by sector on the demand side that can be used to assess the scale of GHG emissions growth in urban SSA to 2050

- Start the process of developing plausible and consistent scenarios, particularly as regards economic growth, and develop initial assessments of the possible impact of mitigation measures under scenario.
- Publish an energy demand side data set into the public domain for SSA
- Attempt to obtain initial insights as to what are critical areas for work to further improve the public state of knowledge on the region for the purposes of energy and climate change mitigation planning.

2. Modelling Assumptions and Approach

2.1. Structure, Data Sources & Key Assumptions

Much of the detail around assumptions has been documented online for Phase 1 as discussed above, particularly with regard to the development of energy intensities from survey data. This paper will address only the development of assumptions around structure, high level drivers and some areas of interest such as the representation of the informal sector.

The UEFM has aggregated countries according to the structure of the International Energy Agency's (IEA) World Energy Outlook model (IEA, 2014) which has informed much of the base data and structure of the UEFM model thus far. This structure includes 47 countries aggregated in 4 regions; East Africa, West Africa excluding Nigeria, Central Africa and Southern Africa excluding South Africa with Nigeria and South Africa themselves represented as a further two individual regions because of their high share of GDP and energy demand (see Appendix A for country detail).

The base energy data used for calibration was sourced from UNdata's Energy Statistics database. This was augmented from other sources including FAO and IEA in instances where data quality seemed questionable, for example as discussed below in respect of residential biomass consumption. Economic and demographic data was sourced from the World Bank and African Development Bank (World Bank, 2016) (AFDB, 2014). The scope of the model is urban and as an initial simplifying assumption, given the limitations to public data, it was assumed that urban GDP can be approximated by national GDP less value added by agriculture and mining. This rests on the premise that with the exception of South Africa, the contribution of manufacturing outside of urban centres in SSA is, in general, relatively small on an aggregate view. GDP Data was available for 18 larger metropoles in South Africa from another project (SEA, 2015c) which enabled a better approximation for that region and future work should address an improved picture for the rest of SSA.

2.1.1. Primary Drivers – GDP and Population Growth

Energy systems models require a large amount of diverse data because of the size and scope of a typical energy system. In general however, the demand for services like lighting, heating or passenger-km of transport in the future are assumed to be linked to one or both of the two key drivers GDP and population growth with the latter being driven in turn by urbanization in an urban model. The assumption of the growth rates of these two drivers, compounding as they do across a decades long window in this type of analysis, generally have a much greater effect on absolute quantities than the myriad of other details. The intention of these types of models is of course not always to predict the bounds of the future but to assess the relative benefits of scenarios of policy intervention against the counter-factual, usually a baseline of 'business as usual'. In this instance however one goal is the estimate of the future potential global share of greenhouse gas (GHG) emissions of the region, so reasonable values are important. Somewhat optimistic projections of long term national economic growth in excess of 6% (SOFRECO, 2011) and even 8 – 10% (ERC, 2011) have on occasion been assumed in planning models of the region and countries in the region. As such, and recognizing the caveat of the primacy of structural considerations in an economic outcome, a first order estimate of the likely bounds of future economic growth were assessed on the basis of the distributions derived from the database of World Bank indicators (World Bank, 2016). These can be compounded for all the permutations allowed between 1961 and 2014 to generate a large dataset of average growth rates for windows from 1 to 50 years for 237 countries as shown in Figure 1 below.

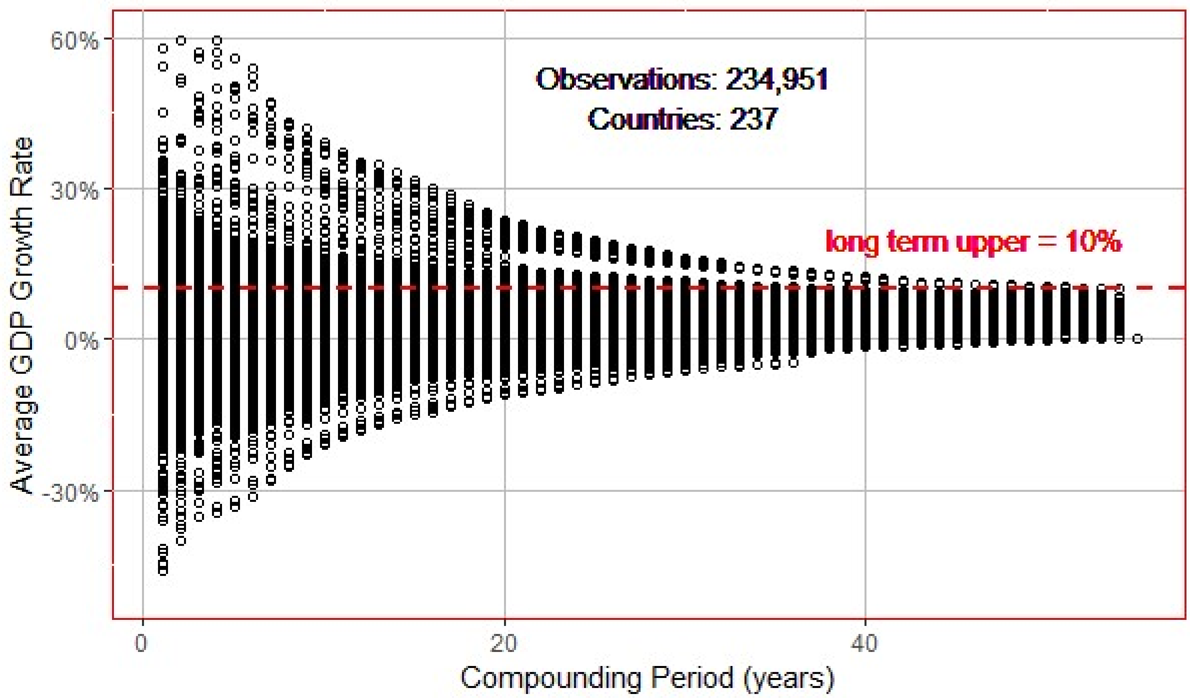

Figure 1: Scatter Plot Illustrating the Convergence of National GDP Growth Rates over compounding time (Source: Author's calculations from World Bank Indicators 1961 to 2014 (World Bank, 2016))

The spread of historical average GDP is very large over a short window, testament perhaps to the futility of short term economic predictions, and still quite large over as long as ten years but has converged considerably by 28 years, the time horizon of the UEFM. Clearly a 10% growth rate compounded over 30 years is extraordinarily high with the economy thus doubling just over every seven years, but this is the exact reason for caution in these assumptions. The probability distribution for this window can be readily generated and is shown in Figure 2 below which contrasts the distributions for Sub-Saharan Africa and the rest of the world (ROW). The mean and 90th percentile are calculated for the whole population.

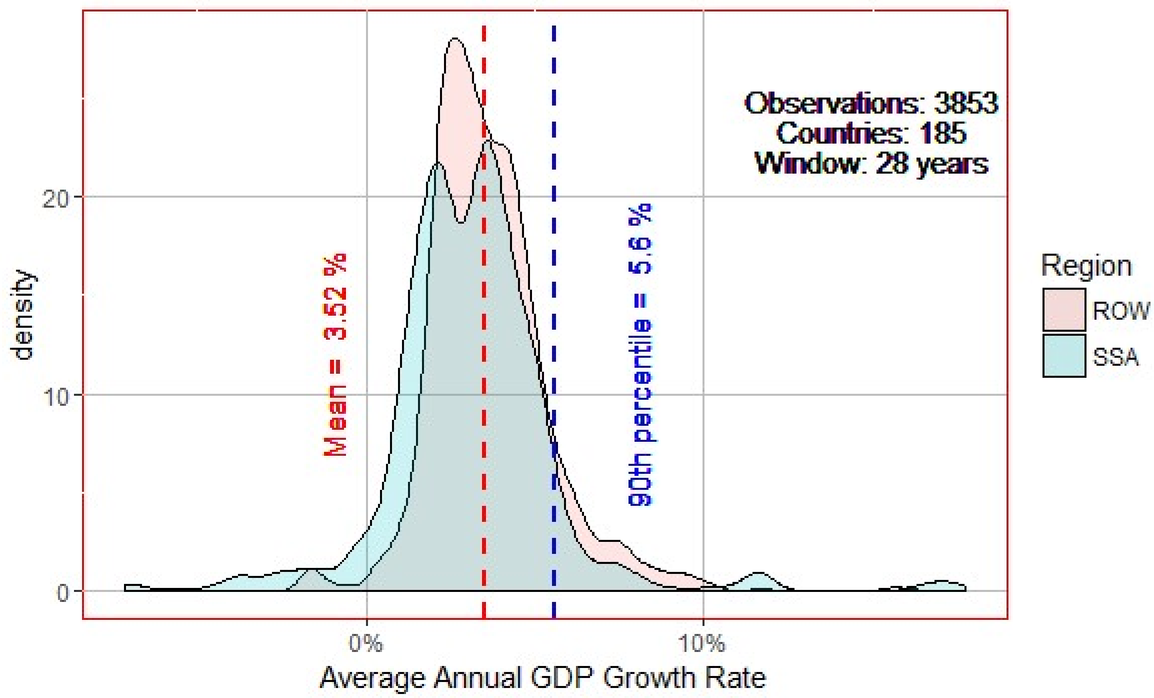

Figure 2: Probability Distribution of Average National GDP Growth Rates compounded over a 28 year window. (Source: Author's calculations from World Bank Indicators 1961 - 2014 (World Bank, 2016))

In general, it appears as if the economic performance of SSA has slightly lagged the rest of the world on average, as might be expected with the inclusion of older data, and that over this long window average, GDP growth has generally fallen between 0% and 6%, but with long tails in the distribution. A similar exercise comparing High-Income countries, as defined by the World Bank, with the rest of the world showed that economies growing off a wide variety of bases are spread across the distribution.

Indications are, therefore, that even given an optimistic outlook on the region that might, for instance, anticipate demand for commodities driving rapid growth that translates into tertiary diversification timeously, a reasonable mid-growth scenario would be between 3.5% and 5%. Compound growth rates over this long period that are in excess of 5.5% can be considered high as indicated by this analysis, especially for an aggregate of a number of countries. Cities being the engines of growth and the recipients of population dividend will however grow faster on average than the national economy as indicated by data for 33 sub-Saharan African cities shown below.

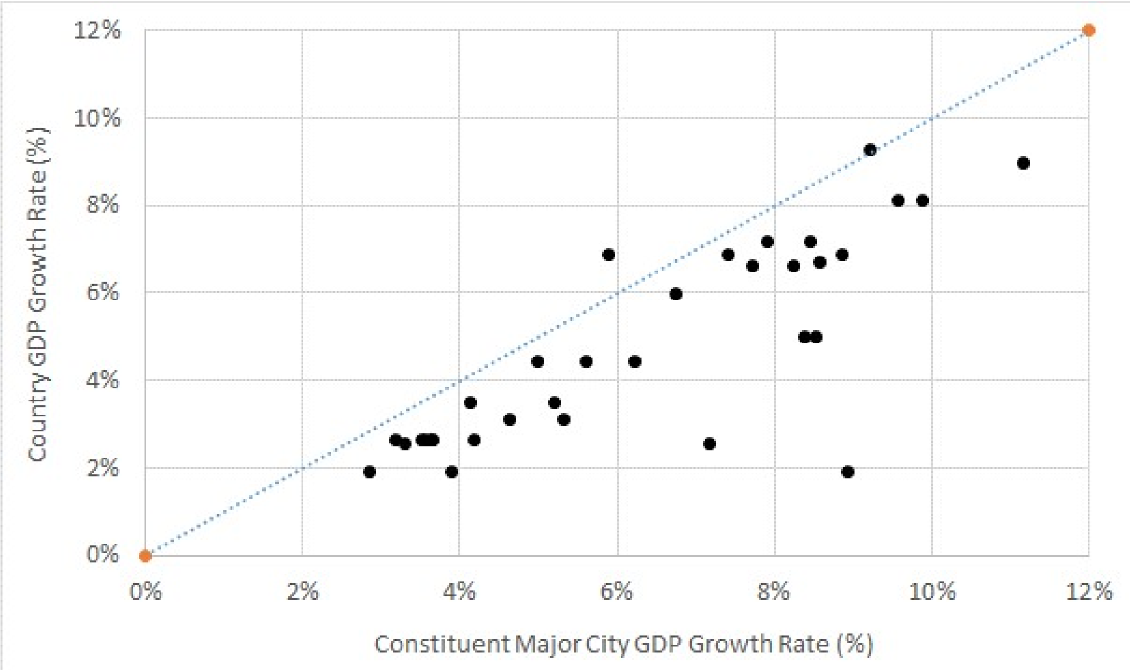

Figure 3: City vs Country Compound Average GDP Growth Rate Comparison for 33 major cities in 16 sub-Saharan African Countries between 2006 and 2012 (Anonymized proprietary data (National Treasury, 2015))

The GDP weighted compound annual growth rates for the countries and the cities between 2006 and 2012 were 4.2% and 5.1% respectively, a roughly 1% difference. An upper limit of 6.5% year on year economic growth rate was therefore adopted in the model as a high economic growth scenario to reflect the upper level of potential emissions increase in urban sub-Saharan Africa.

Quantifying the rate of growth of urbanization in SSA has recently become contentious, particularly for West Africa as explored in the Africapolis project (Moriconi-Ebrard, et al., 2008). This work makes the argument that C\cities in SSA are getting bigger but frequently this is at the rate of natural population growth and with the forces of city immigration and out-migration balancing. The assertion is made that urbanization rates are, and have been, higher in Latin America and Asia and that poor census data in the region has led to reliance on model data founded in their assumptions on the very rapid growth of the 70s when projection models typically under-predicted actual outcomes (Moriconi-Ebrard, et al., 2008) (Potts, 2012) The most detailed population data for the region, including projections, is published on an ongoing basis by UN-HABITAT and replicated in the World Bank Indicators data set. These data and commentary indicate the following (UN-HABITAT, 2014):

- Urbanization growth rates in SSA are the highest in the world particularly for the least urbanized sub-region of the world, East Africa, with a projected urban growth rate of 5.35% for the decade 2010 to 2020.
- The conflicting Africapolis data is acknowledged as well as that the UN data is extrapolated from historical national census data that is sometimes incoherent, widely different in methodology and based on different definitions of "urban". Most of the gap appears to arise from differing allocations of population to smaller urban agglomerations of less than 500,000 people where, in the case of West Africa, by far the greater share of 'urban' dwellers are located. Clearly by their nature these are hard to survey.
- The tables of regional growth rates presented however still show very high levels of growth in the urban share of the population with at least 1% higher annual growth rate in cities projected relative to national growth population.

In developing assumptions for future urban share of population for this study, consideration was given to the probability that an increase in GDP/capita, which seems fairly certain on a regional basis, likely implies that the share of urbanization should increase given that economic growth concentrates in cities. A consistent set of scenarios linking GDP, population, growth sectors of the constituent economies, potential for tertiary economic development and the evolution of urban agglomerations, has yet to be developed for the region and it was therefore assumed for this work that the UN-Habitat projections represent an upper limit on the rate of urbanization, suitable for assessing an emissions increase potential. Lower values may be explored in other scenarios for future work. The key modelling assumptions for the six regions are presented in Table B 1 in *Appendix B – Key Assumptions of the SSA UEFM Model*.

2.2. Modelling the Evolution of the Informal Sector in SSA

The SAMSET Ghanaian survey observed and interviewed a large number of enterprises designated as informal even though the two secondary cities observed are relatively prosperous in terms of the region (Bawakyillenuo & Agbelie, 2014a) (Bawakyillenuo & Agbelie, 2014b). The informal economy is indeed a feature of developing countries and can be both a positive and negative driver of economic development. A relationship between the scale of the informal sector in terms of the numbers of people it employs and GDP/capita has been observed as shown below (ILO, 2012).

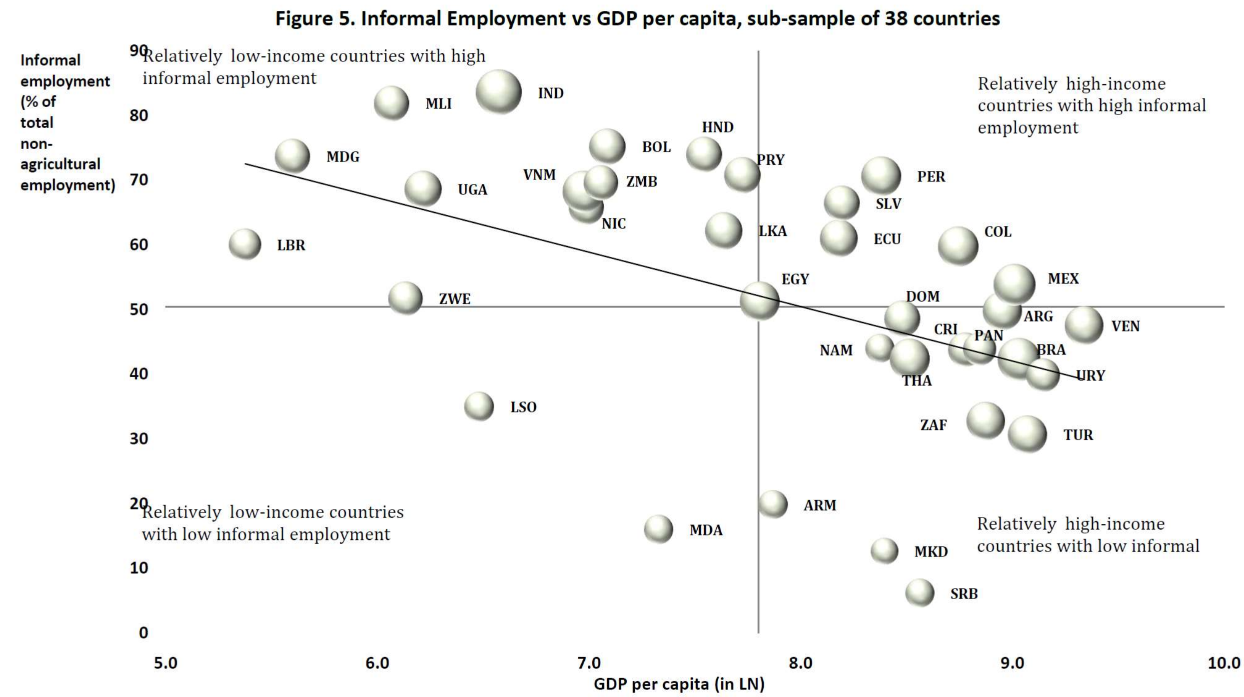

Figure 4: Percentage of Informal Employment in non-Agricultural Sector vs Natural Logarithm of GDP per Capita (ILO, 2012)

The scatter notwithstanding, this provided a tractable basis to model the evolution of the informal sector. This linear relationship was combined with observed informal share of employment data for 8 of the 49 countries in the model (LABORSTA, accessed June 2016) and recalculated into US$ PPP terms as follows:

$$\emptyset_{inf} = -9.58\, ln\left(\frac{GDP}{capita}\ [2005\ US\$\ PPP]\right) + 125.1$$

Where $\emptyset_{inf}$ = The employment share of the informal economy

This yielded the following curves of informal share of the economy over the model time horizon for the high economic growth rate case of 6.5% urban GDP growth and 3.4% urban population growth.

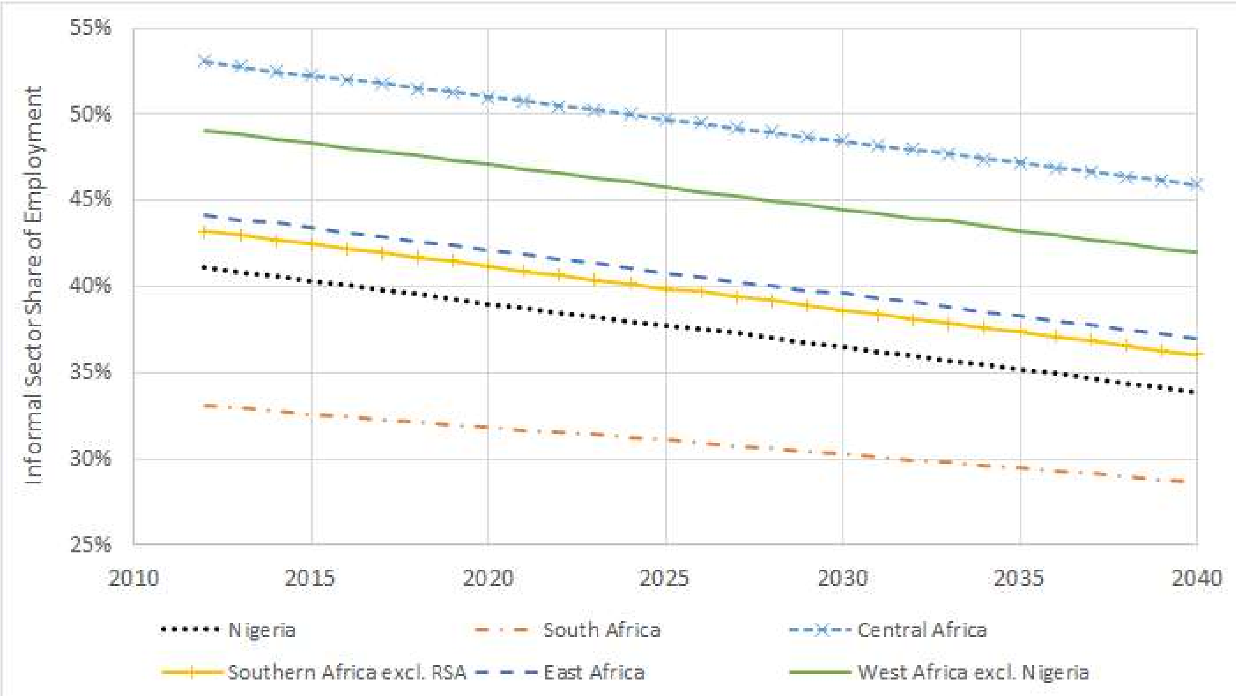

Figure 5: Projected evolution of informal sector employment in UEFM Regions for base case assumptions

These relationships are useful in an energy systems model because by assuming energy intensities for the various fuels on a per capita basis for informal commerce rather than on a per square metre of floor area basis as is general practice in representing formal commerce, we can drive the demand for energy services from this sector in the model in a more practical way. While increasing GDP/capita might drive down the share of informal sector employment in the model, the absolute number of informally employed still increases by nearly 2.9% per annum for a 3.4% urban population growth rate. Many factors will determine the evolution of informality in SSA in future years but this non-structural, purely statistical approach does give the insight that the informal sector may continue to grow substantially despite a high economic growth path and this has implications for all aspects of planning, including that for energy supply.

2.3. Profiling Residential Energy Demand

Demand in the base year, as shown below, is characterized by the dominance of biomass as wood and charcoal in all regions except South Africa which is almost universally electrified in urban areas (SEA, 2015c). Charcoal is a feature of urban areas in SSA although less so in Nigeria and Central Africa. UEFM assumes that on average for SSA 78% of charcoal and 17% of wood used by households is consumed in urban areas.

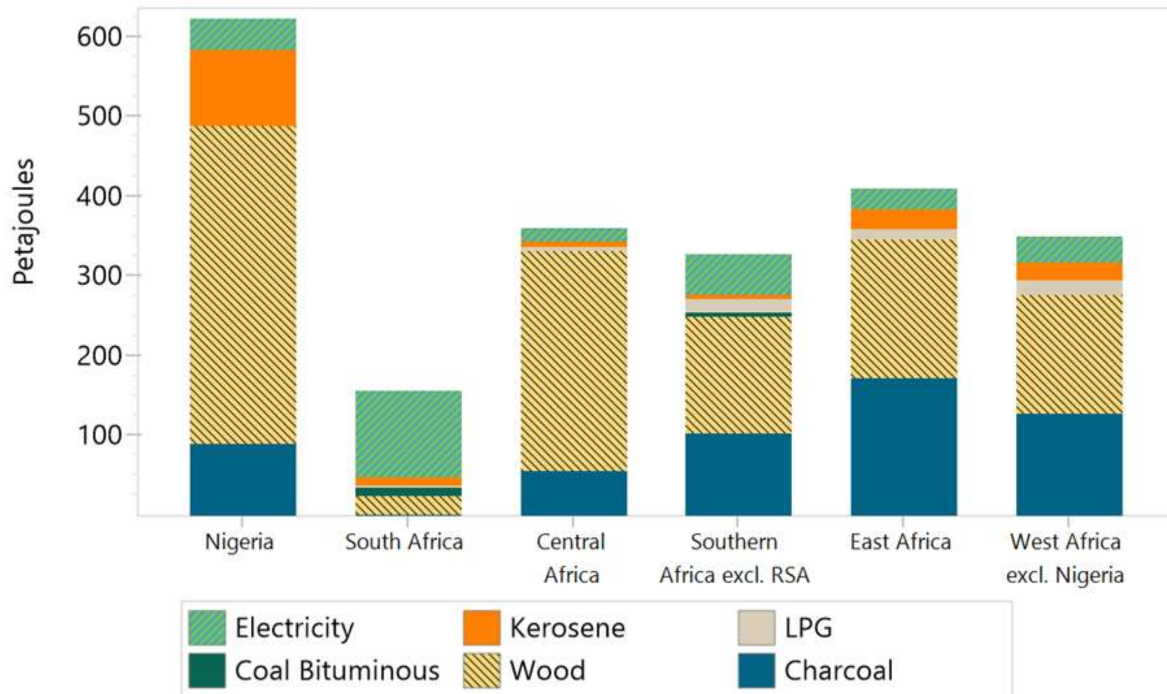

Figure 6: Base Year Urban Residential Energy Consumption by Fuel

The data for wood fuel was sourced from the UNdata Energy Statistics Database (UNdata, accessed April 2016) and the Food and Agriculture Organization's data portal (FAOSTAT, accessed April 2016). There are large discrepancies between UN Stats and FAOStat data for fuelwood particularly for Nigeria and Southern Africa. These two sources were averaged, scaling the FAOStat total by the household/total ratio of the UNStats data and then validated against typical household energy intensities, except for Nigeria and South Africa which were sourced from local studies (DEA, 2016) (GIZ, 2015). Agricultural Residues and Vegetal wastes are included, most of which is allocated by the data to Nigerian Household use. The total wood fuel demand agrees closely with the WEO model (IEA, 2014) although the urban share of demand is moderately lower for UEFM. The Nigerian data suffers from an over allocation of all fuels to households and calibration was problematic. It seems, for example, likely that subsidized household kerosene of which a vast quantity is allocated to households by the energy balance, is rather being diluted into diesel which is very short in the energy balance. Some Nigerian data may therefore be overstated.

These detailed issues aside, clearly then a transition to modern energy in the form of electricity and LPG can reduce energy and emissions intensity significantly, particularly given the relatively high share of hydropower outside of South Africa as well as offering significant health benefits due to reduced exposure to smoke.

2.4. Scenarios

The basic scenarios from Phase 1 (SEA, 2015a) (SEA, 2015b) described in Appendix C have been implemented in the regional model thus far. With the added level of detail, however, increased exploration of interventions in selected sectors by region is now possible with the example of the implementation of an energy efficient buildings scenario methodology described below.

2.4.1. The Energy Efficient Building Scenario

End-use data for commercial buildings was not available for the geographic scope of the model and therefore building standards were used as a basis to assess commercial building energy efficiency potential rather than a bottom-up approach. Future efficient building standards were assumed based on the values for different climatic regions shown below in Table 1.

Table 1: Specific primary energy consumption levels, for heating, cooling, dehumidification, ventilation and hot water: values recommended for closed new building concepts (Moore, Schüwer, & Thomas, 2013)

Building Standard	Cold (e.g. Helsinki)	Temperate (e.g. Shanghai)	Hot and Humid (e.g. Mumbai)	Hot and Arid (e.g. Khartoum)
	($kWh/m^2_{TFA}yr$)	($kWh/m^2_{TFA}yr$)	($kWh/m^2_{TFA}yr$)	($kWh/m^2_{TFA}yr$)
Low Energy Building (LEB)	40 – 80	40 – 80	100 – 150	50 - 100
Ultra-Low Energy Building (ULEB)	20 – 40	20 – 40	50 – 100	25 - 50
nearly Zero Energy Building (nZEB)	0 – 20	0 – 20	0 – 50	0 - 25
Plus-Energy Building (PEB)*	++	++	++	++

TFA: Treated Floor Area
**The estimation energy intensity of PEBs assumed an average of 4 floors, 40% area coverage, insolation of 4.5 $kWh/m^2/day$, 254 generating days and PV panel efficiency of 11%. This resulted in only temperate climate buildings being net generators at the rate of 3 $kWh/m^2.yr$.*

Under an active policy the shares of these in new building stock were assumed to evolve as follows:

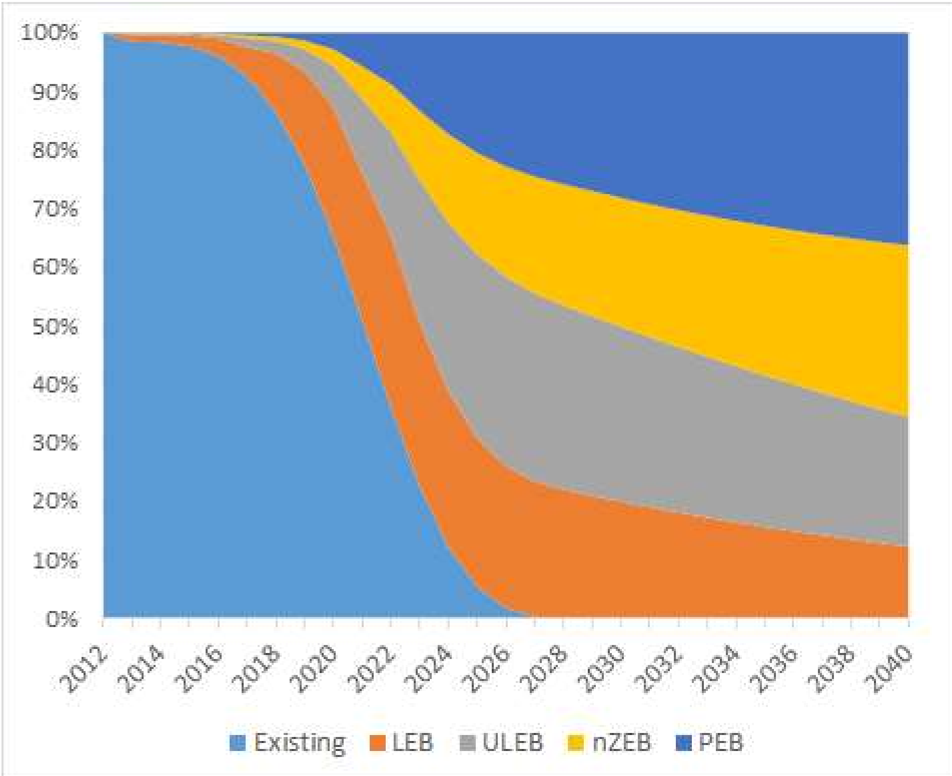

Figure 7: Assumed evolution of new Commercial Building Technology in New Stock under Active Policy Regime

By assuming the energy intensities in Table 1 for the scenario of stock evolution assumed in Figure 7, relative energy intensity curves were generated for new stock and cumulative new stock (approximately the average of new stock for a constant growth rate). The example shown below is for an equal mix of temperate, hot–humid and arid-humid climates but curves were developed for all regions. We assume a 1% scrap rate of old stock to which the model is not highly sensitive given the high GDP growth rate assumptions. We assume the electricity intensity of new stock in the model to be the start year commercial building sector electricity intensity of a region multiplied by the cumulative new stock relative energy intensity (%) such that by 2040, applying the curve below, all new stock since 2012 would have an average energy intensity of 43% of the start value and new stock built in 2040 would have energy intensity of 11% of the start value. This Active Policy Regime scenario assumes then that new stock will use electricity for energy services and is therefore applicable to the formal commercial sector (the model disaggregates formal and informal commerce) and excludes sub-sectors where cooking is significant.

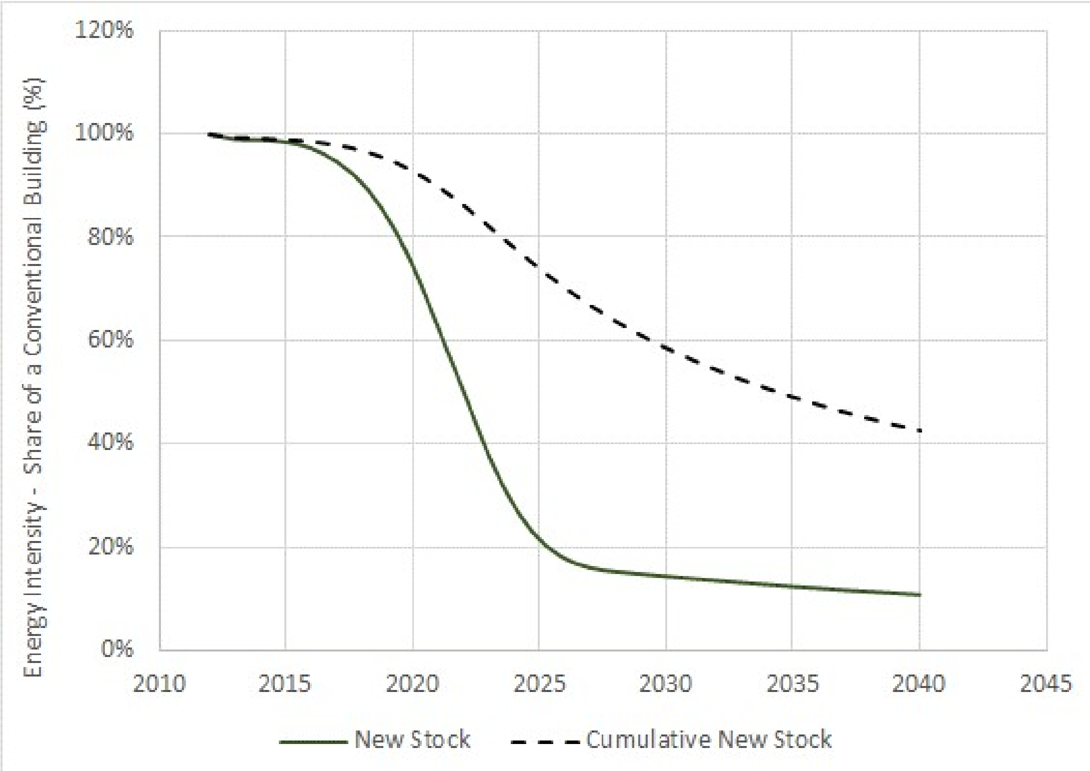

Figure 8: Assumed Shifts in Relative Energy Intensity of New Building Stock under an Active Low Emission Building Programme

3. Results

The results of Phase 1 for a one region model are included below as they give a useful aggregate assessment of the possible evolution of energy use in the region and how where that growth might place SSA's GHG emissions in world terms and broadly how that may be mitigated. The current energy picture as regards demand and supply in the 6 sub-regions will be contrasted and the differing effects of some of the scenarios on the outcomes illustrated with a brief selection of results of simulations with the Phase 2 model.

3.1. Phase 1 Results – The One Region Model

Projecting the current demand forward under Business-as-Usual conditions shows that urban energy demand in sub-Saharan Africa doubles by around 2025 and increases fourfold by 2040 if the current high GDP and population growth rates are maintained. The majority of this growth in demand is within the transport and industrial sectors. Although not shown below, the carbon emissions per sector generally reflect that of the demand, with only a slight change in relative proportions due to the residential sector being responsible for fewer emissions than its proportion of total energy demand.

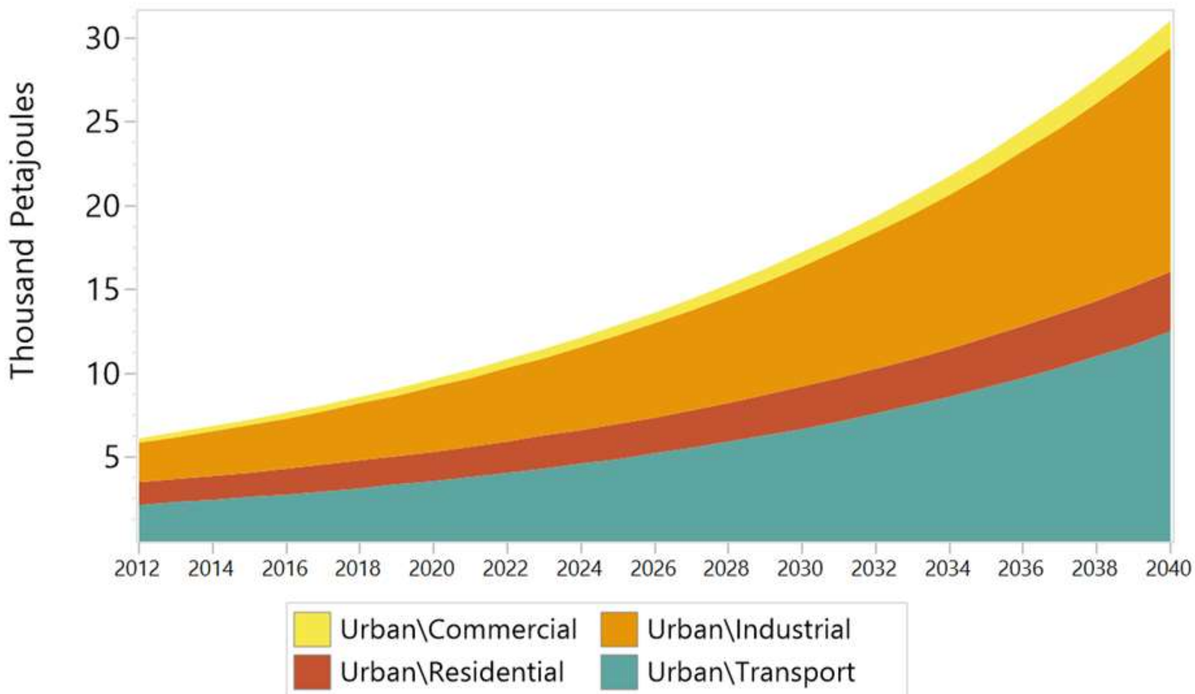

Figure 9: Urban sub-Saharan energy demand over time – Business-as-Usual scenario

With the rapid growth of energy demand in urban sub-Saharan Africa into the future comes a concomitant growth in carbon emissions, with emissions doubling in 2027 and increasing almost fourfold by 2040 in the Business-as-Usual scenario as shown below in Figure 10. The Universal Access scenarios results in only a very small reduction in emissions from Business-as-Usual. Although the scenario moves households from biomass fuels to more carbon intensive modern energy sources such as fossil fuel-based electricity, there is still a small reduction in carbon emissions into the future due to the increased efficiency of modern energy carriers.

Implementing energy efficiency is one of the easiest and cheapest ways to reduce carbon emissions. Implementing cost-effective and well-established interventions in each sector has a large cumulative effect. The Energy Efficiency scenario modelled here reduced carbon emissions by 14% compared to the Business-as-Usual case.

The impact of the Renewable Energy scenario on the carbon emissions of urban sub-Saharan Africa is significant. Due to the contribution of hydro-electric power in the region, the electricity mix is already relatively lower emitting and doubling the share of renewable energy (solar and wind) in the energy mix, as called for by the Sustainable Energy for All targets, has a significant impact. This scenario reduces emissions by 11%. The cumulative effect of the Universal Access, Energy Efficiency and Renewable Energy scenarios is seen in the Sustainable Energy for All (SE4ALL) scenario – it results in a 20% reduction in emissions over the Business-as-Usual scenario by 2040.

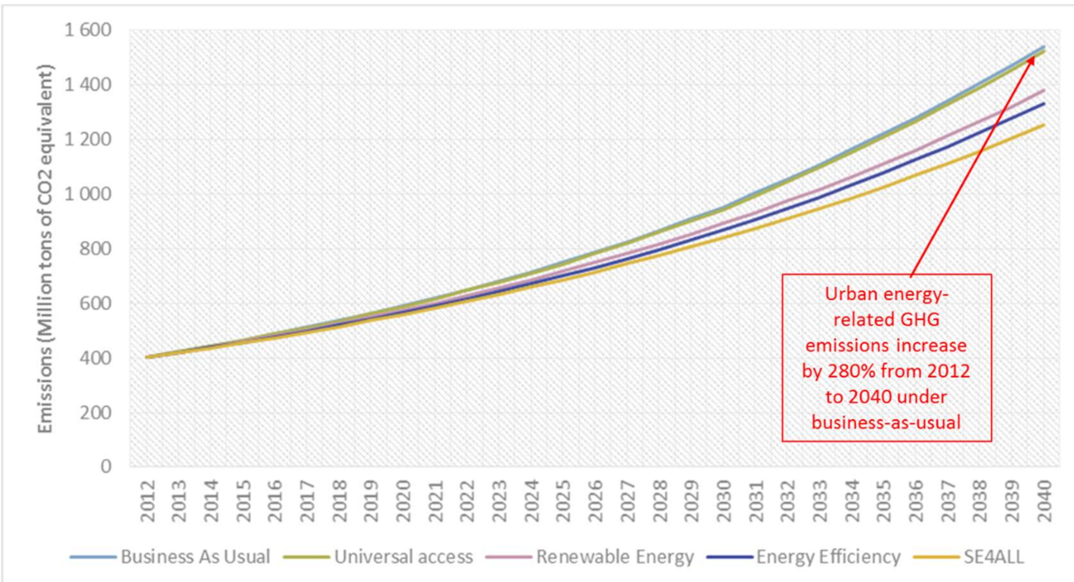

Figure 10: Projected emissions from urban sub-Saharan Africa over time for the Business-as-Usual, Universal Access, Renewable Energy, Energy Efficiency and Sustainable Energy for All (SE4ALL) scenarios

The emissions from the model were compared to those of Representative Concentration Pathway (RCP) 6.0, from the fifth assessment report of the Intergovernmental Panel on Climate Change (Hijioka, et al. 2008). RCP6.0 represents one of the intermediate projection scenarios, although current global emissions are already exceeding those projected by RCP6.0. In the LEAP model base year, 2012, urban sub-Saharan Africa represents approximately 1.2% of global emissions while total sub-Saharan Africa emissions represent approximately 1.8%. By 2040, this has grown to 4%, suggesting that sub-Saharan Africa, and especially urban areas, are likely to account for a more significant share of global emissions.

3.2. Phase 2 Results – The Six Region Model

Figure 7 below contrasts the regional split in demand for energy for all fuels (left) and for modern energy only (right) for the six regions.

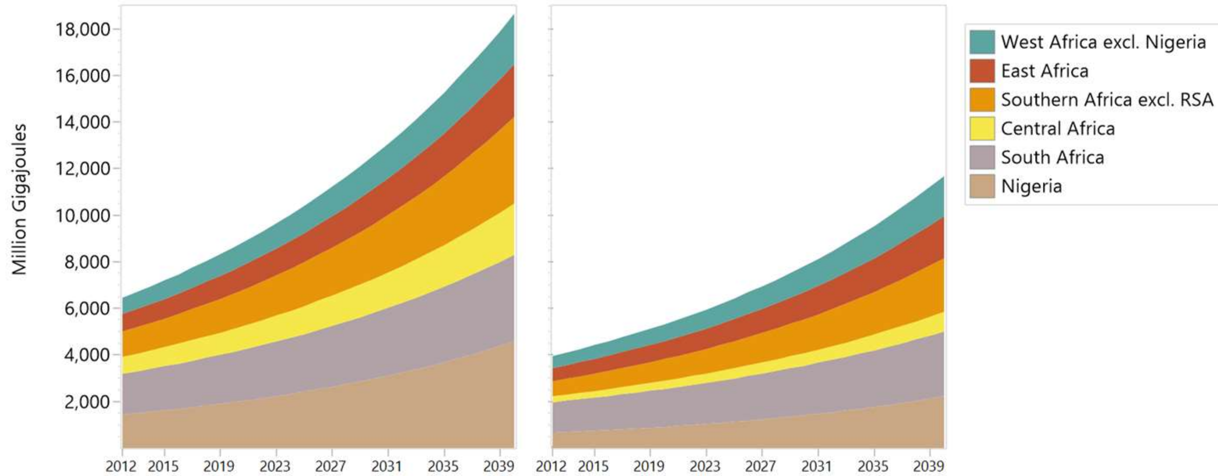

Figure 11: Business as Usual – Regional Distribution of Energy Demand in SSA with Modern Energy only shown right

As is expected, universal urban household access to electricity and LPG has a substantial effect on future energy demand as for example shown in Figure 12 below, the wood fuel and charcoal intensive residential sector in East Africa shows a marked decline in energy demand under this scenario relative to BAU. However, as contrasted in Figure 12, the effect on all regions and across all sectors is substantially more muted.

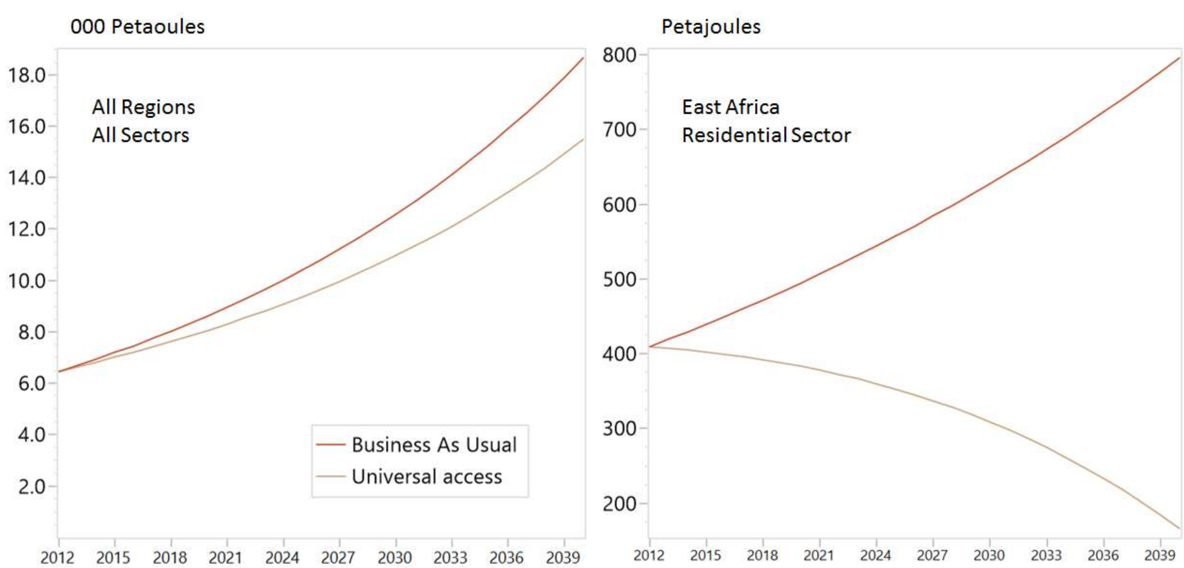

Figure 12: Effect of Universal Access Scenario on Energy Demand of the SSA Energy System Contrasted with Effect on the Residential Sector in the Wood Fuel Intensive East African Region

This is because industry and commerce outside of South Africa are also extremely wood intensive according to official statistics. As shown below for 2040, Nigeria's urban industrial (by our simple definition of non-mining) energy consumption, which is almost 70% of South Africa's, exceeds it by 2040 at the disparate growth rates assumed but it is overwhelmingly wood based. The literature (Bombelli & et al, 2009) (Ciais & et al, 2011) (Valentini & et al, 2014) suggest that the regional GHG forcing effects attributable to wood fuel are primarily significant as combustion with deforestation effects being eclipsed by agricultural land use change. Were even a partial realization of this sort of compound growth in biomass demand to transpire (FAO statistics show this to be currently the case) and combined with the very high use in other sectors observed, it seems likely to be a very severe localized load on West African forests with serious implications for these areas as carbon sinks.

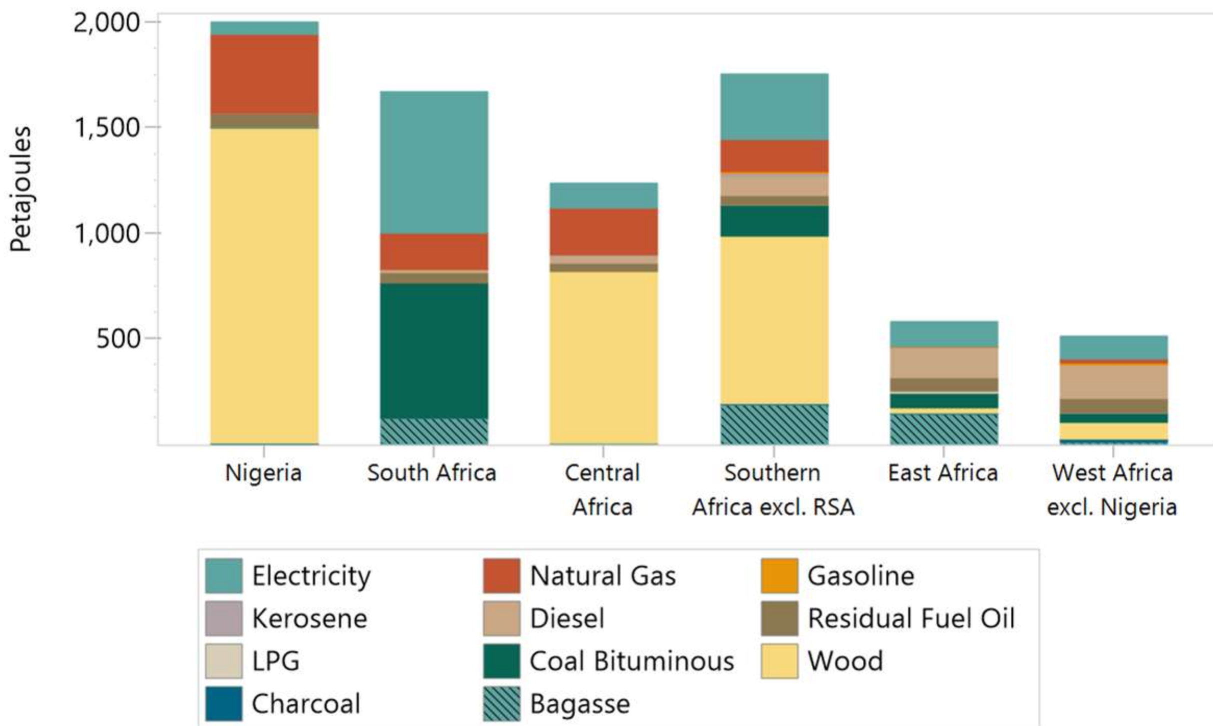

Figure 13: Urban Industry Energy Demand by Fuel by sub-Region Projected to 2020 Under Business as Usual

This speaks to the structural aspects in the discussion about economic growth rates in Section 2.1.1. Energy infrastructure is lacking outside of South Africa and will be needed to drive the industrialization that would be required to sustain the 5.5% national growth rates for 30 years assumed in this modelling. In the 2012 base year, the entire SSA power pool excluding South Africa accounted for around 41 GW of installed capacity (compared to South Africa's 44 GW) with Central Africa supplied by only 4.5 GW of capacity, despite vast potential hydropower resources. While in SSA commercial buildings do not account for a large share of energy demand outside of South Africa, the SAMSET survey and modelling work (McCall, Tait, & A, 2016a) (McCall, Tait, & A, 2016b) has highlighted instances where commerce in sub-Saharan Africa is economically constrained by high suppressed demand and likely underserviced. Energy Efficient buildings that include embedded generation as well as efficiency measures, as explored by the scenario results shown below, can provide SSA with a technology leapfrogging option to unlock economic growth although, investment required for energy efficient and energy positive commercial properties are not trivial investments and much needs to be done institutionally to set this in motion.

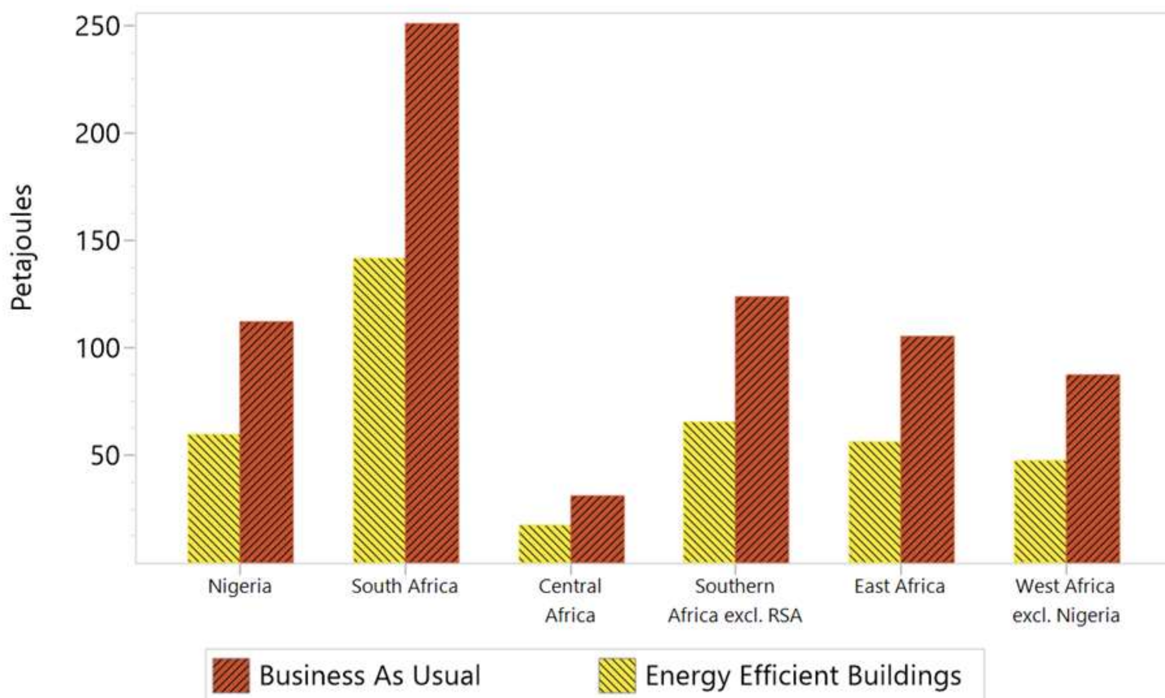

Figure 14: Energy Efficient Building Scenario savings in the Commercial Sector by Region Projected to 2040

The positive effects of a concerted move to energy efficient buildings shown above are to a degree limited in the model by the assumption of a high share of informal commerce (Figure 15 below) that does not benefit from EE policies. The SAMSET survey and modelling work (McCall, Tait, & A, 2016a) (McCall, Tait, & A, 2016b) suggested that suppressed demand in regions where grid electricity reliability is low, impacts the informal sector particularly hard as alternative diesel fueled back-up supply is too expensive and therefore cheaper back-up power systems would be an economic boon for this sector.

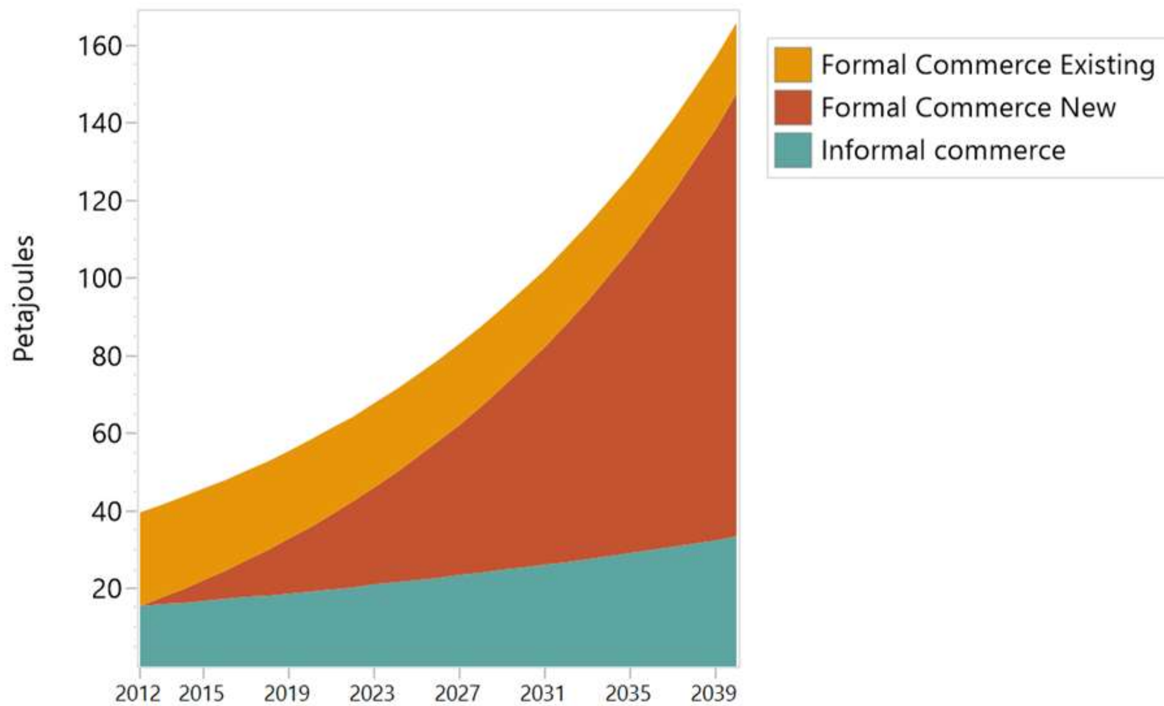

Figure 15: Evolution of Energy Demand from Informal and Formal Commerce for West Africa excluding Nigeria under Business as Usual

The municipal level SAMSET States of Energy surveys and modelling have shown a tendency towards the dominance of transport fuels in the municipalities analyzed in Ghana, Uganda and South Africa with, for example, quite high levels of private car ownership and use in Ghana (Bawakyillenuo & Agbelie, 2014a) (Bawakyillenuo & Agbelie, 2014b) (McCall, Tait, & A, 2016b) (McCall, Tait, & A, 2016a) . This is likely quite regionally specific and transport fuels - while growing to the second biggest share of urban energy consumption in Southern Africa - remain a relatively small share of demand in for example, Central Africa, as shown below, even though the BAU model assumptions around private car use drive an increase in private transport share of energy (not passenger-km) from 60% in 2012 to over 80% in 2040.

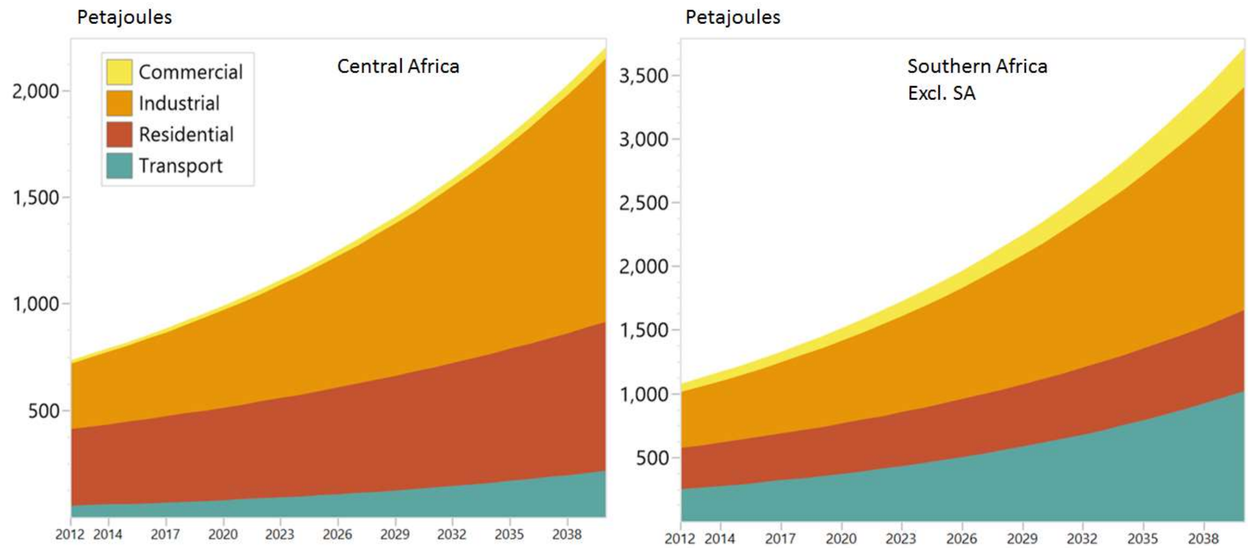

Figure 16: Comparison of the Evolution of the Sector Share of Urban Energy Demand for Southern and Central Africa under Business as Usual

The current version of the model however projects a demand for passenger-km simply in proportion to urban GDP and may therefore underestimate the growth in transport energy for regions like Central Africa. This is because at a certain GDP/capita threshold, private car motorization has been seen to accelerate non-linearly with GDP/capita (Dargay, Gately, & & Sommer, 2007) and so growth in the demand for private transport may be faster than the rest of the economy as a greater share of household consumption is directed towards this sector. Transport has become a vexing source of emissions, energy costs, balance of payments problems, and accidents, injuries, and fatalities in much of the world, albeit a ready source of taxation in times of fiscal shortfall. This work as shown below indicates that public transport shares enjoy a firm majority in all regions outside of South Africa except for Nigeria which has a very high motorcycle population that is difficult to distinguish as private or public.

Table 2: Modelled Public Transport Shares of Passenger Transport of Regions in SSA (2012)

Indicator	***Central Africa***	***East Africa***	***Nigeria***	***South Africa***	***Southern Africa excl. ZA***	***West Africa excl. Nigeria***
Share of pkm (%)	69	65	59	56	68	64
Share Pass. Energy Demand (%)	19	18	12	13	18	20

**Based on bottom-up modelling using vehicle fleet estimates from the World bank Ronet Model calibrated to UN Stats demand for petrol and diesel*

The table above illustrates the potential role of investment in electro-mobility and new forms of public transport such as bus rapid transit and rideshare facilitated by transit orientated development to keep the public share of passenger km high and energy demand relatively low (SSATP, 2015) .

4. Conclusions

The initial results and data from the Urban Energy Futures Model of sub-Saharan Africa presented here bring some regional perspective to energy use patterns and issues of access to modern energy and supply constraints. Greenhouse gas emissions are likely to grow several fold but remain relatively small in global terms although it is of great concern that still fast growing wood fuel and charcoal use are a component in reducing the continent's action as a carbon sink. Universal access to modern energy coupled with improved electricity supply are clear priorities as is known. Leveraging new energy technologies in the form of cheaper and more sustainable back-up, home supply and mini-grid systems and low emission buildings with embedded generation may however hold out the promise of improved access that can open up the economic diversification required to sustain economic growth rates into the future with improved lives and livelihoods. Transport too is key and it is to this area that the next phase of work will turn as well as to improvements to the representations of residential and electricity supply as follows:

- Transport: Add detail in the form of a stock model that can realistically assess the uptake of new technologies, a more rigorous model of motorization growth and the development of detailed scenarios of sustainability measures and their costs.
- Electricity Supply: Apply the large body of work on electricity supply, such as the outputs of the TEMBA model to improve scenarios and also to move the model towards a 'with current policies' baseline approach rather than 'business as usual' where current power sector emissions are extrapolated unrealistically. Least cost optimization will be applied in the power sector of the model whereas currently capacity shares are simulated.
- Residential Sector: Complete the splitting of households across income groups linked to energy services, comparable across countries and develop a consistent set of scenarios of GDP, household income, income distribution and population growth

It is hoped that the SAMSET model of local data collection and documentation within the framework of a partnership with in-country tertiary institutions and municipalities will expand such that a continually developing picture at different levels of urban aggregation unfolds and local data collection can continue to be leveraged to generate improved information and insights on the supply of energy services in a range of environments and urban settlement types to aid decision making and understanding.

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Appendix A – Regionalization of Countries in SSA

Table A 1: Regional Scope of the SSA UEFM Model

Region 1: Central Africa	**Region 2: East Africa**	**Region 3: Southern Africa excl. South Africa**		**Region 4: West Africa excl. Nigeria**	
Cameroon	Burundi	Angola	Mauritius	Benin	Guinea-Bissau
Central African Rep.	Djibouti	Botswana	Mozambique	Burkina Faso	Liberia
Chad	Eritrea	Comoros	Namibia	Cabo Verde	Mali
Congo	Ethiopia	Lesotho	Seychelles	Côte d'Ivoire	Mauritania
Dem. Rep. of the Congo	Kenya	Madagascar	Swaziland	Gambia	Niger
Equatorial Guinea	Rwanda	Malawi		Ghana	Sao Tome and Principe
Gabon	Somalia	United Rep. of Tanzania		Guinea	Senegal
	South Sudan	Zambia		Togo	Sierra Leone
	Sudan	Zimbabwe			
	Uganda				
Region 5: South Africa					
Region 6: Nigeria					

Appendix B – Key Assumptions of the SSA UEFM Model

Table B 1: Key Socio-Economic Indicators for UEFM Model by Region for UEFM Base Case – Year 2012

Indicator	***Central Africa***	***East Africa***	***Nigeria***	***South Africa***	***Southern Africa excl. ZA***	***West Africa excl. Nigeria***
GDP (Constant 2005 bill. US$ PPP)	190.5	437.1	795.4	576.7	435.0	286.1
GDP/ Capita (Constant 2005 US$ PPP/pp)	1,642.7	1,710.6	4,727.6	11,018.2	2,497.2	1,817.4
Agriculture, Mining & Utilities (% of GDP)	52%	40%	39%	15%	34%	38%
Estimated Urban GDP (Constant 2005 bill. US$ PPP)	90.7	263.2	489.0	488.9	288.3	177.3

Population (mill.)	116.0	255.5	168.2	52.3	174.2	157.4
Urban Population (mill.)	49.3	56.5	76.1	33.1	56.2	63.8
Urban Population (%)	42%	22%	45%	63%	32%	41%
Urban Electrification Rate (%)	50%	72%	62%	97%	60%	71%
Rural Electrification Rate (%)	8%	9%	34%	67%	7%	15%
Household Size	5.0	4.9	5.1	3.6	5.0	5.3
Population Growth Rate	2.4%	2.4%	2.4%	1.8%	2.4%	2.4%
Urban Population Growth rate (%)[1]	3.4%	4.3%	3.4%	2.3%	3.4%	3.4%
Urban GDP Growth Rate (Upper) (%)	6.5%	6.5%	6.5%	5%	6.5%	6.5%

1: See discussion above. Can be considered an upper estimate appropriate as our base case is intended as an upper estimate of energy demand and emissions

Appendix C – Description of Scenario Measures

Note: All interventions outlined below were modelled as being implemented by 2040.

1. UNIVERSAL ACCESS

This scenario only affects the residential sector, with a move away from more traditional fuels such as charcoal, coal and wood to modern fuels such as electricity and LPG.

Cooking

- Share of households using electricity increased from 12% to 45%
- Share of households using LPG increased from 26% to 50%
- Share of households using coal decreased from 1% to 0%
- Share of households using wood decreased from 28% to 1%
- Share of households using charcoal decreased from 82% to 4%
- Share of households using kerosene decreased from 8% to 0%

Lighting

- Share of lighting from lantern's decreased from 46% to 0%
- Share of lighting from incandescent light bulbs increased from 27% to 50%
- Share of lighting from CFL light bulbs increased from 27% to 50%

2. ENERGY EFFICIENCY

Lighting

- Share of lighting from lantern's decreased from 46% to 0%
- Share of lighting from incandescent light bulbs decreased from 27% to 10%
- Share of lighting from CFL light bulbs increased from 27% to 90%

Appliances

- Energy intensity for refrigeration decreased by 20%
- Energy intensity for water heating decreased by 30%
- Energy intensity for "other" decreased by 10%

Commercial

The same energy savings were used for all sub-sectors. The percentage reduction in energy intensities were taken from the State of Energy in South African Cities (SEA, 2015c):

- Energy intensity for lighting decreased by 40%
- Energy intensity for HVAC decreased by 25%
- Energy intensity for water heating decreased by 30%
- Energy intensity for refrigeration decreased by 5%
- Energy intensity for "other" decreased by 5%

Industry

The average percentage reduction in energy intensity for all electricity interventions, from the City Mitigation LEAP modelling (SEA, 2015), was 15%. Therefore, the energy intensity for electricity was decreased by 15%

Transport

- Energy intensities of all private transport modes was decreased by 10%
- The proportion of public passenger transport was increased from 77% to 80% by 2040. This intervention is attempting to model a change in urban form to allow the retention of such a high proportion of public transport.

3. RENEWABLE ENERGY

A doubling of the proportion of renewable energy in electricity supply

4. SUSTAINABLE ENERGY FOR ALL

A combination of all the measures above.