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A brief BIOsketch

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Abstract

For decades, Africa was generally perceived as the dumping ground for obsolete technologies. In recent years, technological leapfrogging which is associated with the newly industrialised economies in Asia has transpired in some key industries. In this article, we present the solar photovoltaic industry as one such industry and an integrated model of scaling up solar technologies. We identified five unique models aimed at scaling up solar energy in Africa: state-led, NGOs and other agencies-led, emerging market multinational enterprises-led, Avon and pay-as-you-go models. Our analysis focused on four countries (Ghana, Nigeria, South Africa and Kenya) in particular, and Africa, in general. Despite the promising opportunities of this industry, a number of factors such as high up-front capital costs and limited end-user financing schemes have limited the technological process. We conclude by outlining the implications of the findings for theory and practice. Key words: Africa; sub-Saharan Africa; solar; technology; policy; technological leapfrogging

Introduction

> "The sun is hugely powerful—it delivers more energy in an hour than humankind uses in a year and unlike fossil fuels it will never run out" (The Economist, 2011b, p. 20).

In the first decade of the 21st century, solar energy emerged from the shadows and the gloomy picture of Africa's geological environment to become not only a major source of power, but also a platform on which new businesses and opportunities flourish (Bradford, 2006; Kulichenko & Wirth, 2011; The Economist, 2011a; World Bank, 2008). Globally, there are around 1.4 billion people without access to grid electricity but who enjoy sunlight most days of the year. Harnessing solar power is not only fundamental to poverty alleviation, but also economic development. Solar photovoltaic (PV) energy provides people disconnected from the global economy and without access to power grids with the opportunity to light their homes and businesses in places where grid power can either be extremely expensive or unreliable (International Trade Forum (ITF), 2011; The Economist, 2012a). This is particularly important given that around 600 million people in Africa, which is around 70% of the population, remain unconnected to the energy grid and rely on expensive and inefficient sources of energy such as candles and kerosene to power their businesses and homes (ITF, 2011; Karekezi & Kithyoma, 2002). Current projections indicate that unless the trend is reversed more than 700 million Africans could be living without electricity by 2030 (ITF, 2011).

In the past few years, the price of solar PV panels have decline by as much as 50% largely due to soaring production in China and significant technological breakthroughs (Birnbaum & Faiola, 2012; KPMG, 2012). The cost of solar PV systems has fallen to the point that it has become a lower-cost alternative to other sources of energy such as nuclear (Blackburn & Cunningham, 2010; Powers, 2010; REN21, 2012). Many in African rural areas get power from diesel generators at prices of roughly $1 per kilowatt-hour, relative to below 20 cents per kilowatt per hour (kWh) for solar PV power (Chipman, 2011). In addition, the quality of solar products such as solar lamps now outperforms the commonly used kerosene lanterns across much of the developing world (Chipman, 2011).

Despite these developments, our understanding of why the solar revolution has failed to take off in a significant way in Africa has been overlooked. The solar PV industry like many others in Africa is characterised as underserved, under-exploited or under-utilised with potential for growth (Amankwah-Amoah, 2014; Amankwah-Amoah & Debrah, 2010, 2011). Against this backdrop, we seek to address three fundamental questions that have remained unanswered: How has the solar industry evolved in Africa? What are governments' policies in this area and models in scaling up solar power? More importantly, what are the major obstacles to scaling up solar power in Africa? We contend that the falling prices and technological breakthroughs of solar PV energy provide an enticing opportunity not only for rural areas, but also for cities to circumvent the conventional path of energy development and move directly to solar energy.

To streamline our analysis, we focus on four sub-Saharan African countries (i.e. Ghana, Nigeria, South Africa and Kenya) which have seen remarkable economic growth in the past decade in Africa (For details on all countries' GDP growth rates, see The Economist, 2013). These four countries are regarded as emerging economies in Africa. We also shed light on those key questions by drawing heavily on illustrative cases and policies from these countries to drive the analysis. We contribute to the literature by advancing an integrated model of the solar scaling up process which includes the state-led, non-governmental organisations (NGOs) and aid agencies-led, emerging market multinational enterprises (EMMNEs)-led, Avon and pay-as-you-go solar models.

The rest of the paper is organised along the following lines. Next, we review the literature on technological leapfrogging and diffusion. This is then followed by an examination of the policies adopted by the four countries towards the industry. Then, we examine models aimed at scaling up the technology to underserved communities. The penultimate section examines the major obstacles in scaling-up solar power in Africa. We conclude by examining the implications of the findings.

Theoretical underpinning: technological leapfrogging

The notion of technological leapfrogging is grounded in the assertion that some emerging countries can acquire and develop the necessary technical and managerial know-how that enables them to leapfrog older vintages of technology by skipping investments in old and inefficient technologies to the future technologies (Comin & Hobijn, 2004; Frow, 1994;

Gallagher, 2006; Hobday, 1995; Lee & Lim, 2001; Perez & Soete, 1988; World Bank, 2008). In a similar vein, technological leapfrogging is a process through which newly emerging countries circumvent the resource-intensive and expensive form of economic development by skipping to "the most advanced technologies available, rather than following the same path of conventional energy development that was forged by the highly industrialised countries" (Gallagher, 2006, p. 383). Technological leapfrogging entails not only the skipping over generations of technologies, but it also means jumping ahead to become a leader (Brezis, Krugman & Tsiddon, 1993; Goldemberg, 1998; Gallagher, 2006; Liu et al., 2011; Soete, 1985).

A major research theme indicates that unlike the old infrastructure technologies such as fixed-line telephone systems, which were subjected to the budgetary pressures of governments as the main provider, new technologies such as the internet and mobile phones are delivered within the regulatory framework that foster market competition and promote private capital (James, 2009; World Bank, 2008). For instance, the mobile phone provided opportunities for many developing countries to develop by skipping landline and associated infrastructure and development costs (James, 2009; Coster, 2011).

Technological diffusion to both low-income countries and advanced countries has historically been a lengthy process. Recent studies indicate that the "pace of technological progress is determined mainly by the speed with which already existing technologies are adopted, adapted, and successfully applied domestically, and done so throughout the economy, not just in the main cities" (World Bank, 2008, p. 105). Across a range of technologies, the adoption period has shortened significantly in recent years leading to the introduction of cutting-edge technologies to the developing world and isolated communities (Comin & Hobijn, 2004; Frow, 1994; World Bank, 2008). Table 1 indicates that the time it takes for technology to achieve wider geographical coverage has shortened significantly for a range of older technologies such as railroads and telephones and newer technologies such as personal computers and mobile phones. In the 1800s, a new technology could take as long as 100 years to diffuse to 80 per cent of the world's countries, however, new technologies now reach 80 per cent of the countries within 20 years (Comin & Hobijn, 2004; World Bank, 2008).

Insert Table 1 about here

Recent changes in the regulatory environment in many developing countries such as privatisation, liberalisation and deregulation have encouraged the development of the private sector and thereby removed many of the barriers and accelerated the rate of technological diffusion across the world (James, 2009; World Bank, 2008). In addition, a country's human capital endowment and the economic conditions play a major role in a country's ability to leap to the next generation technology (Comin & Hobijn, 2004; Gallagher, 2006; World Bank, 1998, 2008). This therefore requires government investment in skills and training to help facilitate technological diffusion (Binz et al., 2012; Goldemberg, 1998; World Bank, 2008).

A line of research has suggested that rapid technology diffusion and successful utilisation partly depend on the economic situation of the end user (Attewell, 1992; Perez-Aleman, 2011). This strand of research takes the view that diffusion and ability to leapfrog are largely "cost and benefit analysis such that the higher the cost, the slower diffusion will occur" (Attewell, 1992, p. 2). Therefore, where the initial cost of transferring to the modern technology is high, consumers in low-income economies may be reluctant to switch. Research also suggested that the public resist the adoption of new technologies due to lack of information about the products and their functionalities (Attewell, 1992; Soete, 1985; World Bank, 1998).

A burgeoning stream of scholarly works now recognise that emerging economies do not necessarily replicate the traditional technological development path of advanced countries, but rather skip some stages and even create their own paths to establish competence in new and growing industries (Gallagher, 2006; Goldemberg, 1998; Hobday, 1995; Lee & Lim, 2001; Liu, Cheng & Chen, 2011; Murphy, 2001; World Bank, 2008; Wu & Mathews, 2012). Despite this recognition, how countries' environment evolves technologically and leapfrog has not been fully explored (Binz, Truffer, Li, Shi & Lu, 2012; Lee & Lim, 2001; Hobday, 1995; World Bank, 2008). In addition, past studies are still unclear about the conditions that facilitate technological leapfrogging and the scaling-up process (Binz et al., 2012). In this paper, we address this deficiency in existing literature by examining the technological leapfrogging and scaling-up process in Africa's solar PV industry.

Solar energy: A global focus

The technologies in the industry have involved since the 1950s and include PV, concentrating PV and concentrating solar power (CSP) (Nevin, 2012; Wu & Mathews, 2012). We focus the analysis on solar PV power generation, which entails the conversion of solar energy or sunlight directly into electricity rather than the distinctive troughs used in concentrated solar power technology (direct sunlight) common in the Middle East (McGrath, 2012; Vaughan, 2012). The leading technologies in this area include the crystalline silicon, thin film and organic compounds including dye sensitised solar cell (Wu & Mathews, 2012). Solar power plants' design may include commonly used PV panels or thermal plants to generate power. Global PV installations increased by 40 % to 27.4 gigawatts (GW) in 2011 and solar cell production rose above 29.5 GW, up from 23.0 GW in 2010 (Solarbuzz, 2012). In 2011, around 30 GW of new solar PV capacity accompanied the growth in the industry and thereby increased the global total by 74% to around 70 GW (See Figure 1). In 2011, the global solar

PV industry generated $93 billion in revenues, an increase of 12% year on year (Solarbuzz, 2012; Montgomery, 2012).

Insert Figure 1 about here

In 2011, the global investments in renewable energy reached $260 billion, an increase of 5% on 2010 and a dramatic improvement from the $53.6 billion in 2004 with investments in solar energy outstripping wind and others (KPMG, 2012). Although the top five solar PV markets (i.e. Germany, Italy, China, the United States and France) accounted for 74% of global demand in 2011, the market has surged in Africa and is projected to become one of the fastest growing markets (Solarbuzz, 2012). In the last few years, China has overtaken their Western counterparts to become the world's largest manufacturer of solar panels with the competition dwindling as US major players such as Evergreen Solar, BP Solar and SpectraWatt filed for bankruptcy (Bradsher, 2010; REN21, 2012).

Over a relatively short period, China has evolved from being a "minor player" in the solar power industry to become the "benchmark" for competitiveness with many of its firms such as Yingli Green Energy, Suntech Power, JA Solar, Suntech Power and Trina Solar seen as the leading players in the industry (REN21, 2012; Bradsher, 2010). Although Germany has historically had a strong reputation in the domestic solar industry, China has recently emerged as the world's largest solar panel maker and exports to European, North American and African markets (Inman, 2012). In 2011, China exported around 60% of its solar panels and components to the European Union generating €21bn (Inman, 2012). The Chinese have been able to achieve this partly due to low labour costs, ability to digest technologies developed in the West, huge economies of scale and government support in the form of subsidies and preferential treatment.

The evolution of the solar PV industry in Africa

For decades, the scorching sun in sub-Sahara Africa was regarded by many as of little economic value or a hindrance to development. In the last few years, this perception has changed fundamentally with the burgeoning technologies in solar energy such as thin-film PV cell and the increasing diffusion of those technologies to developing countries (Walsh, 2008; Wu & Mathews, 2012). These developments have provided the much needed breakthroughs to exploit the potential of solar energy across the continent. Indeed, the thin-film PVs have in recent years moved from the laboratory as young technology to mass production in the industry (Walsh, 2008). This technology is associated with low defects, greater flexibility and low costs in comparison with the crystalline ones commonly used in most solar panels (Walsh, 2008). The emergence of these technologies and their availability to developing economies means that the cost of solar panels has declined to all-time low in recent years relative to alternatives (Blackburn & Cunningham, 2010).

However, the costs are often complicated by numerous tax reliefs, loan guarantees and subsidies offered by governments not only in emerging economies such as China and Brazil, but also in advanced economies including Germany and the United Kingdom (Powers, 2010; Rosenthal, 2010). In 2010, total investment in Africa's renewable energy, including solar, increased to 3.6 billion – a record high, largely due to a surge in countries such as Egypt and Kenya (KPMG, 2012). Across the continent solar systems generally include hospital, household and business consumptions to reduce the reliance on power grids which often fail, leading to major disruptions in cities (Karekezi & Kithyoma, 2002). Globally around 5% to 6% of solar panels producing electricity do not feed into a national energy grid (Noury, 2011).

In the past few years, sales of solar energy devices such as solar lanterns, attic fans and outdoor lighting have surged largely due to falling prices attributed to overcapacity (Platzer, 2012). The increasing utilisation of solar energy has become a symbol of Africa's emerging economies but, more importantly, help to provide the enabling platform for poverty alleviation and economic development. Unlike many industries that have lost their competitive edge and seen remarkable decline such as textiles and manufacturing, Africa's solar sector has seen remarkable evolution to becoming an engine for economic development in the 21st century. For decades, many African cities and villages relied largely on environmentally unfriendly products such as kerosene lamps to power their homes (Coster, 2011). Indeed, Africans spend around $10.5 billion a year on kerosene to provide lighting for their off-grid businesses and homes (ITF, 2011). Solar lighting products generally offer better low-income energy, a cost-effective and cleaner alternative to the widely used kerosene.

Comparative solar energy development

Although South Africa, Nigeria, Ghana and Kenya have replicated their Asian counterparts in promoting solar energy, they appear to lag behind. In the following sections, we take each country in turn and describe their approaches towards the industry.

South Africa

In the mid-1990s in the immediate post-apartheid era, there was an over-supply of electrical power and therefore, there was little sense of urgency for the government to diversify the sources of supply (Nevin, 2005). By 2005, the growing economy in tandem with a burgeoning middle class increased demand. This meant that capacity peaked around 40,000 megawatts (MW) per day, far higher than the 35,000 MW provided by the sole energy provider – Eskom (Nevin, 2005; Oche, 2012). The shortages of the past influenced the government's policy to diversify the sources of energy to meet the needs of industry and homes. Around 90% of electricity generation come from coal-fired power stations (Edkins, Marquard & Winkler, 2010b; Sharife, 2008). In a relatively short period since the end of apartheid, the country has emerged as the largest solar market in Africa and one of the leading destinations for investment in solar energy, panel installations and building of new solar plants.

South Africa's recently proposed solar park in the Northern Cape Province combines both the PV and CSP technologies. The park is expected to create around 12,300 construction jobs and 3,000 in technical areas such as operations and maintenance (Nevin, 2012). The plant is the brainchild of the state power utility Eskom, the government and the Clinton Climate Change Initiative to bring technology to help improve the living standards of people in the country. Solar parks are like industrial development zones with a range of incentives such as government-underwritten labour costs, subsidised land purchase and special tax rates to attract local and foreign investors (Nevin, 2012). In these parks, solar plants are built in clusters, sharing common transmission and infrastructure, which allows economies of scale to be achieved (The SA Government News Agency, 2010).

Global solar panel makers, investors and developers see South Africa as a gateway to the African market. In this respect the region's largest economy has attracted numerous Western and Chinese investors who see the market as offering the best opportunity to establish a foothold and building capabilities for further expansion in Africa (Edkins, Marquard & Winkler, 2010a). For instance, Hanwha Solar One and Suntech Power recently announced plans to build large solar farms in addition to projects to develop solar panels to connect the 12.5 million people currently not connected to the grid (Wang, 2012).

Nigeria

Nigeria is one of the leading oil producers in the world. This has historically not encouraged politicians to devote their limited resources towards alternative sources of energy. Despite over five decades passing since gaining independence and a population of around 167 million, the country continues to struggle to generate 5000 MW of electricity from the dilapidated dams in contrast with South Africa’s 40,000 MW per day (Oche, 2012). This is particularly important given that the Nigeria Atomic Energy Commission recently indicated the oil and gas deposits will be depleted in the next 25–50 years and there is, therefore, a need to diversify sources of energy such as solar and wind to help meet future demands (see Emmanuel, 2012). Chronic acute power shortages characterised by high levels of corruption and mismanagement have stifled the development of new plants and alternative sources of energy (Adenikinju, 2003; Oche, 2012). Indeed, between 1999 and 2007, an estimated $16 billion bid to refurbish the ailing power sector was squandered through corruption, awards of dubious contracts and opaque bureaucracy (Oche, 2012). The country currently has an energy deficit of 23,000 megawatts with an estimated cost of around $1.3 billion a year to the economy. The power problem is severe such that some studies have indicated that several working hours are lost due to power outages leading to low productivity and thereby harming the competitiveness of manufacturing firms in the country (Adenikinju, 2003).

Nigeria is no exception. Indeed, over the “past four decades, the gap between energy supply and demand in Africa” has actually widened in sharp contrast to other developing countries where the gap has actually narrowed (UNIDO, 2009, p. 7). In spite of the rapid economic growth in the last decades, depleting fossil fuels, unreliable sources of energy and continuous blackouts pose major challenges to Africa’s development and its ability to compete with the rising powers of Asia and Latin America (see UNECA, 2007). In light of these developments, renewable energy has emerged at the forefront in the government’s policy to bridge the gap between demand and supply and to help meet the energy challenges faced by the country. Nigeria’s solar panel industry is largely sustained by a private-public partnership programme and investments.

In 2012, the Korean firm, HQMC Korea Company Ltd, announced a plan to invest $30 billion to build 10,000 megawatt solar photophobic panel plants and other solar thermal technology in the country over 10 years (Williams, 2012). This is partly the fruit of the Nigerian Investment Promotion Commission's drive to attract foreign investors into renewable power projects. The project is expected to require 83,999.99 hectares of land and create around 10,000 jobs (Williams, 2012). The Korean firm brings with it expertise from the solar sector and plant developments. In a similar vein and in the same year, construction began on the 30 mega watts of solar-powered electricity project to help address the inadequate power supply in Katsina State (Mamah, 2012). The project is supported by the German Energy Commission. Accordingly, these developments are part of an attempt to address the power shortages.

In 2011, a turning point was reached when the National Agency for Science and Engineering Infrastructure received the backing of the Federal Government to start a rare project of the production of solar panels in the Niger Delta region aimed at creating jobs and ensuring efficient utilisation of local engineering and technical expertise in the area (NASENI, 2012; Abdulhamid, 2011). This is expected to make the country self-sustainable in producing 25MWs worth of solar panels annually for the domestic and export markets as well as discouraging their importation (see Abdulhamid, 2011). This project is in addition to the other manufacturing plant – Karshi Solar Panel Plant, Abuja – which produces a 7.5MW solar panel for export and is one of very few projects in Africa with others located in countries such as South Africa and Senegal (NASENI, 2012; Abdulhamid, 2011). However, limited accesses to modern technologies in the industry and imports of subsidised solar panels from Europe and China have affected the competitiveness of domestic solar panel manufacturing. Despite government commitment, local firms lacked the technological expertise required to develop and manufacture solar equipment such as panels and lanterns on a large scale.

Ghana

Like the rest of sub-Sahara Africa, Ghana is well endowed with an abundance of sunshine. The country receives sunshine duration of 1,800 hours to 3,000 hours per annum making it a friendly environment for solar energy to flourish (Ghana Energy Commission, 2009). Since 2000, various governments of different political colours have adopted numerous policies toward renewable energy sources including special tax regimes, subsidies for investors and feed-in tariffs (i.e. where the government guarantees the investors a set price for power sold to the national grid (The Economist, 2011b). An important feature of the evolution of the industry was exemplified in 2012 when Blue Energy, a UK-based renewable energy firm, announced a $400m project to build a 155MW solar PV plant to be operational by 2015 (McGrath, 2012). The Nzema project, as it is known, seeks to power around 100,000 homes as part of the government's effort under Ghana's Renewable Energy Act to grant premium, feed-in tariffs for 20 years and to help boost renewable energy capacity from 1% in 2012 to 10% by 2020 (McGrath, 2012; Vaughan, 2012). The project is expected to create more than 700 jobs in the country with spin-off effects on industries such as construction and education. The Ghanaian case provides some evidence that with stronger government incentives and policy framework, foreign investors are more likely to be attracted to the sector.

An economic growth rate of around 14% in 2011 was largely attributed to the discovery of oil. This has provided the much needed resources to help diversify the economy away from the over-dependency on hydro-electricity towards renewables such as solar and wind. Despite the growth of solar power, around 92% of solar-electrified households in the country use solar lighting in tandem with the traditional kerosene lanterns to address all their lighting requirements (Obeng, 2007). It's therefore essential to scale up solar in the country. In 2007, the ECOWAS conference on peace and security in Ouagadougou adopted the Ouagadougou Declaration. The declaration laid the foundation for the establishment of the ECOWAS Regional Centre for Renewable Energy and Energy Efficiency (ECREEE) in 2009 with support from the Spanish Agency for International Development Cooperation, the Austrian Development Cooperation and the United Nations Industrial Development Organization (ECREEE, 2010). The programme seeks to invest in renewable energy projects such as solar as a means to reduce poverty and address climate issues. These facilities are available to communities in Ghana and Nigeria, which are leading members in the organisation.

Kenya

Kenya is one of the few countries in Africa that has been relatively successful in the solar PV business focused on small home and commercial systems "to the exclusion of larger commercial or grid-connected systems (large-scale system, >50 MW), which has led to an annual PV market of 1.5 MW dominated by small products" (Hankins, 2011). The country is noted for its strong business (un-subsidised) market, where domestic users choose low power (10–20W) entry-level modules (Solarbuzz (2012). In the 1980s, the declining prices of PV systems encouraged many multi-lateral organisations and donor aid programmes to fund PV-powered projects in Kenya and other African countries (see Duke, Jacobson & Kammen, 2002). This was largely driven by the high upfront cost for poor households and lack of government support to purchase the system.

By 1990, Kenyan household consumption accounted for around 40% of all PV solar sales (Duke et al., 2002). Consequently, today most of the sales in the country are accounted for by the private sector. Recent estimates indicate that there are between 200,000 to 350,000 solar PV home systems in use in the country (Disenyana, 2009; Kenya Ministry of Energy, 2004). The commitment towards renewable energy is rooted in solid government policy towards creating an environment to attract not only foreign investors but also to foster and stimulate local entrepreneurship. One of the government policies towards technological diffusion is duty-free importation of renewable energy hardware and building the capacity of local firms for domestic and export market by 2024 (Disenyana, 2009; Kenya Ministry of Energy, 2004). Today, it can boast of having one of the largest private sector-led PV markets in East Africa and a major player in PV solar home system sales in Africa (Disenyana, 2009; Hankins, 2011).

Insert Table 2 about here

As illustrated in Table 2, compared with Kenya and South Africa, Ghana's attraction of foreign investors has been largely driven by government supports with little private involvement. In terms of number of installations, South Africa has made major progress with around 150,000 installed PV systems, and Kenya between 200,000 to 350,000. To date, the two countries have the highest documented installed capacities of solar PV systems. Indeed, Kenya is regarded as one of the countries in the world with the highest rates of solar panel systems installed per capita and uptake of solar panels is surging ahead of connections to the traditional electrical grid (Eveleens, 2011). On the other hand, Ghana and Nigeria lagged behind Kenya and South Africa but are certainly among the growing number of African countries including Tanzania that have devised strategies and incentives to attract foreign investors in the renewable energy sector. The optimism for the nascent solar industry has been buttressed by the numerous national and regional initiatives aimed at unlocking the potentials of this industry.

However, they lack comprehensive initiatives aimed at equipping manufacturing firms to gain technological capabilities rather than relying mainly on imports. Of the four countries the vast majority of African solar panel manufacturers are located in South Africa with players such as Micro Care, MLT Drives, Rentech, Setsolar and Solairedirect Technologies.

In this direction, Kenya is among a few countries on the continent that offers attractive tax incentives to manufacturers of renewable energy technologies to help domestic capacity building (Disenyana, 2009). This is in line with energy strategies devised elsewhere such as China, the US and Spain to facilitate solar development; offering such tax incentives are seen to attract private investors (Chan, 2012). This is predicated on the fact that technology leapfrogging largely depends on the country's ability to attract investors as well as create the environment that encourages the adoption of solar power as a better alternative for consumers, businesses and entrepreneurs.

Insert Table 3 about here

As demonstrated in Table 3, countries such as Nigeria are among a growing number of countries in Africa and have employed state capital to start state-owned solar firms to allow local manufacturing facilities to develop. The case of Ubbink East Africa is a small-scale module manufacturing firm that has emerged in the PV cell and module business across the continent that facilitates collaboration between local and foreign companies for domestic manufacturing (see Table 3). The growing government support for these small-scale module manufacturing firms provides only a limited window of opportunity for them to gain a foothold in the market given growing competition from Chinese, South Korean and Taiwanese firms in the industry (Barker, 2012).

Models for scaling up solar energy

Having set out key features of policies in the four countries' part of the state-led model, this section examines the distinctive models that have emerged for scaling up in this growing industry: non-governmental organisations (NGOs) and aid agencies-led, EMMNEs-led, Avon and pay-as-you-go solar models. These models have made solar power increasingly "more accessible and affordable to those at the bottom of the pyramid" (The Economist, 2012a, p.14-16).

NGOs, aid agencies-led model

A substantial part of development in the industry such as the building up of solar markets has been largely delegated by governments to NGOs and aid agencies such as the World Bank, United Nations and Global Environment Facility (Hankins, 2011). From the four countries, South Africa and Kenya have been largely championed by the private sector and the coverage of PV in the countries; whilst Ghana and Nigeria have recently adopted policies in this direction (see Table 2). For instance, the Lighting Africa programme began in 2006 with a Global Environment Facility grant as a joint initiative of the International Finance Corporation and World Bank with the aim of helping to ensure utilisation of solar energy. The programme which has been piloted in Kenya and Ghana seeks to mobilise the private sector to connect isolated communities to give power to 250 million people by 2030 to enhance economic development (ITF, 2011). The programme seeks to help off-grid communities to gain access to light. In 2010, over 134,000 portable solar lamps were sold across the continent providing more than 672,000 people with lighting (ITF, 2011, p. 18). The programme helps to address gaps in the market, where investors are reluctant to provide finance to producers and manufacturers to introduce off-grid power generation products. It also offers market information to financial institutions to alert them to growth potentials of this emerging sector.

A number of multi-nationals, as part of their corporate social responsibilities, have unveiled initiatives aimed at boosting communities' access to solar power. This was exemplified by the recent case of Cadbury investing approximately $1.3 million in the installation of 10,000 solar lanterns and panels for cocoa farmers in 160 communities in Ghana (Renewable Energy Magazine, 2011; Whitmore, 2011). This is under the Cadbury Cocoa Partnership which seeks to bring small-scale solar technology to cocoa farmers and isolated communities. Other beneficiaries of the solar panels scheme include schools, clinics and food-processing sites to enhance local power generation (Renewable Energy Magazine, 2011; Whitmore, 2011). Although such donor assistance and solar NGOs are warranted in some areas, there is a real need to shift away from donor-led projects to commercial and productive investments which allow viable private sector firms to thrive (Hankins, 2011). In this direction, markets for small solar systems less than 100wp are essential in helping low-income earners overcome initial high costs. It provides an avenue towards creating self-sufficient farmers and workers.

Emerging markets multi-nationals-led model

Emerging Chinese multi-nationals such as Hanwha-SolarOne, Trina Solar, Yingli Green Energy and JA Solar have recently emerged as major players in the scaling-up process in Africa either through exports or plant development contracts. The low cost-base, ability to absorb technologies developed largely in the West, prior experience of operating in emerging markets, cheap labour and availability of low-cost engineering and manufacturing talents have enabled them to alter the competitive landscape. They are undercutting established Western firms by offering low-cost solar panels. The rise of these firms has led to innovations that allow solar PV panels and lanterns to be delivered to consumers at much lower cost and thereby improve their geographical coverage and their competitiveness. These are a new breed of global firms which are creating opportunities for themselves and providing communities in Africa with access to solar products to develop.

Avon model

One of the most attractive business models that has recently been replicated in the industry is the Avon model. It takes its roots from the late 19th century, “Avon ladies” which started in the US with door-to-door sales or direct-sales of cosmetics products (The Economist, 2012b).

This model has been replicated with the "phone ladies" in rural Bangladesh and now Solar Sister which started in East Africa for the sale and distribution of solar products such as solar lamps (Kermeliotis, 2012; The Economist, 2012b). Solar Sister recruits and trains women in East Africa by providing them with access to these jobs and empowering them through economic opportunities. It provides an opportunity for women without gainful employment to start their own social enterprises using a network of contacts to sell solar lamps in rural communities (The Economist, 2012b). Such initiatives are essential in empowering women in Africa. The Solar Sister model has expanded to Kenya, Uganda, Sudan and South Sudan to help reach even the remotest parts of the continent. The model generally seeks to help alleviate energy poverty by encouraging consumers to switch from the expensive and hazardous use of kerosene and candles for lighting to solar lighting and other products such as solar lamps (Kermeliotis, 2012).

Although solar lighting systems cost around $50 or $60, the vast majority of the poor in the developing world cannot simply raise such an amount and require some kind of incremental payment method which the pay-as-you-go model offers (Murray, 2011). Firms seeking to gain the innovation edge must be able to "blend in" with their customers to allow diffusion of information and respond to the customer's requirements (Esty & Winston, 2006). The Avon model provides such a link between the producers of solar panels and their customers which helps in not only the design, but also pricing to attract their demand. The blending-in process provides information about customers and thereby sharpens the manufacturer's "senses about potential customer problems and possible solutions" (Atuahene-Gima, 2012, p. 51–52).

Pay-as-you-go solar model

As demonstrated in Table 2, in all the four countries, high up-front PV solar installations costs serve as a major deterrent in their adoption of the technology. An innovative financing technique, pay-as-you-go model, has emerged to help the poor gain access to solar energy at their homes and small businesses. One of the services is offered by Eight19, a solar firm supported by the UK-based Carbon Trust, IndiGo (African Business, 2011; Murray, 2011; Price, 2012). Eight19 offers solar energy equipment to off-grid communities and people to gain access to power on a rental basis (Murray, 2011; Price, 2012). The business model works this way:

> *"Customers add credit to their IndiGo solar power device using a scratchcard validated on a standard mobile phone through a text message. Using a mobile phone payment system eliminates the problem of cash collection and while IndiGo customers currently use scratchcards, as mobile banking expands, they could eventually pay directly through their mobile phones"* (Murray, 2011, p. 28).

The pay-as-you-go model is where individuals and firms in isolated areas are connected to power through the solar PV panels' projects and in return make payments to help sustain the operations. The model focuses on incremental payment for solar panels and lanterns which allow the poor to gain a foothold and eventually eliminate expensive kerosene and generators as sources of power for their businesses and homes (African Business, 2011). The agreement allows the users to lease or rent a solar PV system. Solar power provides opportunities for developing countries to avoid using inefficient and unreliable sources of energy such as kerosene and move directly to renewable energy such as solar lights to enhance their economic development (Coster, 2011; Macguire, 2012). In Kenya, Eight19 sells solar equipment such as light-emitting diode lamps, batteries and phone chargers for around $10 and then charges customers a dollar a week to use them rather than the $2 a week they are currently spending on kerosene (Murray, 2011; The Economist, 2012a).

In addition to the technical innovations and technological breakthroughs that have occurred, financial innovations such as these new methods of buying installation systems have improved the accessibility of solar power across the four countries. However, there are a number of problems inherent in this business model. It creates dependency on the firm and consumers may end up paying several dollars more than the market value. There is a real need to empower people at the base of the pyramid to be self-sufficient in the provision of electricity. Given that one fifth of the world's population lacks access to electricity via a grid, a unique opportunity exists for the new model to develop further. Next, we examine some of the barriers to the scaling up of solar power in Africa.

Barriers to scaling up of solar technology

Solar energy provides isolated communities with some kind of "grid independence" to counter the unreliable sources of power and experiences of rolling blackouts especially in Ghana and Nigeria. Indeed, solar power has challenged utility companies and "democratize energy generation" by turning isolated homes and small firms into "energy generators" (Crane & Kennedy Jr., 2012, p. A35). This empowers individual consumers to control their power generation, which has been the major driving force in scaling up the solar revolution (Bradford, 2006, p. 17). The economic and social cases for solar technology in empowering communities to generate their own power and remove the reliance on national and regional grid lighting are robust (Bradford, 2006; The Economist, 2012a). Figure 2 provides the framework for our analysis about the business model and the scaling-up processes, and the effects of solar technology on individuals, entrepreneurs, firms and governments.

Insert Figure 2 about here

However, there are a number of obstacles to scaling up the technological leapfrogging in the four countries. First, unlike consumers in the West who can afford the upfront costs of solar panels on their roofs to generate electricity, the majority of African in desperate need of solar power can hardly afford such an investment even though there is a very strong economic and environmental case for solar power (The Economist, 2011a). Indeed, "over 90% of the lifetime cost of a solar PV system is paid up-front" at the time of installation, which is beyond the reach of most people in Africa (Bradford, 2006, p. 137). As shown in Table 2, a lack of financing in low-income countries often stymie the spread of technology within national borders as well as constrain government's ability to develop the human capital necessary for the technology to spread (see also World Bank, 1998, 2008).

In addition, many global companies are generally reluctant to allow their technologies to diffuse to the local economy which may alter the competitive landscape (Fu & Gong, 2011) and thereby limit developing countries' ability to acquire and utilise such technologies to develop (Atuahene-Gima, 2012; Gallagher, 2006). The solar industry in now dominated by major Chinese, European and US producers. This makes it difficult for knowledge and expertise in the industry to diffuse to the local firms. Another barrier to technological leapfrogging is the government's taxes and policies which have made electrification of towns by solar energy expensive (Marlow, 2009). There has been little attempt on the part of governments to promote production of solar panels in Africa, with notable exceptions detailed earlier.

Discussion and conclusion

In this article, we have examined the evolution of the solar industry, governments' policies and barriers to scaling up solar technological leapfrogging in Africa. We identified five main models aimed at scaling up solar energy in Africa: state-led, NGOs and other agencies, EMMNEs, Avon and pay-as-you-go. Through examination of governments' policies, we found that despite incentives such as tariff relief and subsidies, access to private capital, high up-front PV solar installations and limited end-user financing schemes posed major challenges to the leapfrogging process. Kenya and South Africa are the trendsetters in attracting and utilising private capital to enhance development of solar energy, which can be replicated by the other countries. The recent developments in Ghana and Nigeria provide an indication of steps towards building capabilities in this area. The analysis demonstrates that the four countries have made significant strides in devising strategies to leap to large-scale solar sources of power generation. Promising signs such as the recent decline of solar PV panel prices and technological improvements have ushered in a new landscape accompanied by new businesses models that have emerged to enhance coverage and affordability of solar energy to the mass population (Noury, 2011).

Our analysis contributes to the growing body of literature on technological diffusion (Gallagher, 2006) by delineating the mechanisms through which market conditions and government policies influence the scaling of new technologies. We also make a modest contribution to the current literature on economic development by presenting an integrated model of solar scaling up in Africa, which elucidate the scaling-up processes, mechanisms and constraints. The article adds to the burgeoning stream of research which suggests that Africa's future partly lies in its ability to unlock the potential of solar energy and its people to address the current climate change challenge (Karekezi, 2002; UNIDO, 2009).

Implications for practice

There are a number of practical implications stemming from our analysis. First of all, although innovation is essential to Africa's future (Atuahene-Gima, 2012), much of the research and development (R&D) activities on the region remain loosely connected to economic and development projects. The industry demands capacity enhancement through R&D, education and training to develop the skills of locals to support economic growth and foster innovation not only within the four countries, but also across the continent. This also means a training and support system for solar energy engineers and technicians to help manage and maintain solar equipment. Our research suggests that there is a need to engage in joined-up thinking, which requires close collaboration between government departments and agencies to bring together technical and managerial expertise to unlock the potential of the sun (see Perraton, 2009; MacKenzie, 2012).

Governments could incentivise local construction firms to install solar systems in new infrastructure projects. Such actions would provide a much needed boost for the industry and create jobs in areas such as construction, installations and repair services. As countries strive to facilitate this technological leapfrogging, there is a need to remove restrictions on the adoption of solar generation such as access to finance for the local area, government support programmes and education to raise awareness of the technologies available.

In addition, the analysis suggests the need for governments to establish regional solar energy zones as demonstrated in South Africa's case, where firms could enjoy additional tax relief and access to free public land especially in rural areas. Such priority areas would create green jobs by unleashing new opportunities for PV manufacturers, developers and installers. Another implication of the analysis concerns the role of government support in harnessing solar energy to unlock the potential of Africa's manufacturing base. Given that China and Taiwan accounted for 74% of global cell production in 2011, an increase from 63% in 2010 (Solarbuzz, 2012; Platzer, 2012), there is an urgent need for capability building to help local firms gain a foothold and acquire mastery in solar technologies in this growing industry. This would help to revive the dying manufacturing industries across the continent. In the haste to generate a solar industry, there is a real need on the part of African governments to ensure that they do not lavish unjustified subsidies on foreign investors which may translate to an uncompetitive industry in the future.

Our analysis also indicates a need to promote collaborative ventures between local firms and foreign investors which would lead to the diffusion of knowledge to the local partner. Such an approach would provide local firms with access to world-class knowledge which could propel African countries to the solar technological frontier. There is an intrinsic tension between creating conditions to attract investors on one hand and the need to create conditions that facilitate technological diffusion and foster growth in the nascent industry on the other. Reconciling these objectives requires a long-term strategy of encouraging collaboration between domestic and foreign companies. Finally, this study indicates a need to shift away from the current NGOs-led approach to improve PV coverage towards initiatives that allow small businesses and new markets to emerge. Despite the noble works of NGOs, the future must be driven by private-public investments as demonstrated in Kenya. The analysis also points to the need to invest in energy storage to ensure full utilisation of power generated. As isolated communities become connected to solar power, there is a need to connect domestic solar power generation to the national grid to provide consumers with the opportunity to sell extra solar power back to grids (Karekezi & Kithyoma, 2002).

A limitation of the study is that governments' policies for the industry tend to differ which leads to different scaling-up paths and constraints. Therefore, the findings may not be generalised to other emerging economies. Another limitation is that the scaling-up process and model articulated here might not be suitable for the introduction and scaling up of other technologies in Africa. We recommend that future research seek to include more countries and different industrial sectors in assessing the generalisability of the findings. In closing, we hope that, in some small way, this article not only serves to encourage governments to create the conditions that facilitate the technology advancements of African firms, unlock the potential of the sun and reduce dependence of fossil fuels. We hope that this article encourages more scholarly works in this area.

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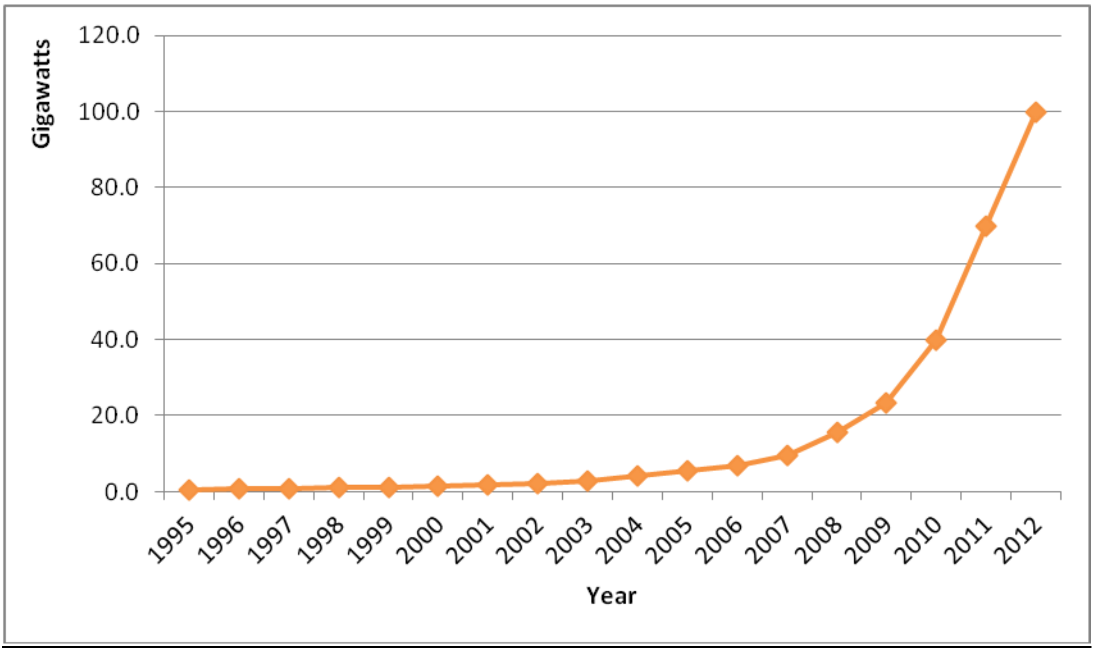
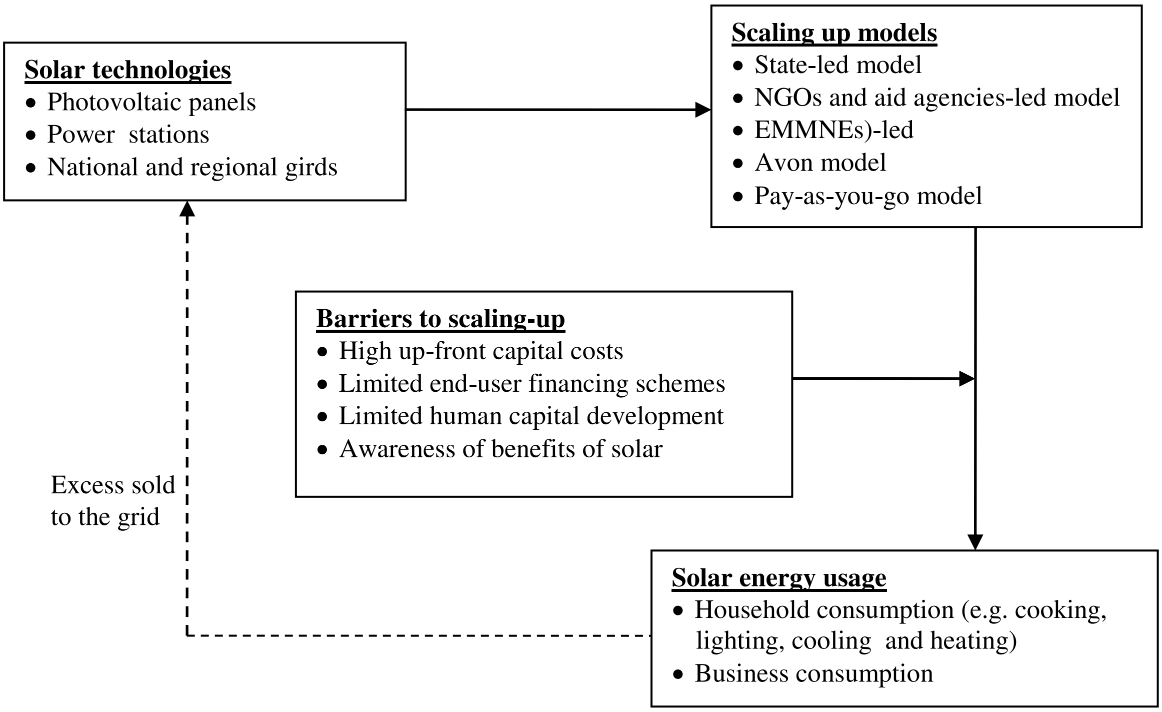
Figure 1: Solar PV Total World Capacity, 1995–2012



Data source: REN21 (2012, 2013)

Figure 2. Solar scaling-up model



Notes: The dotted lines are used to indicate that this is largely underdeveloped or non-existing market in Africa but potential to grow in the future.

Table 1: High-tech leapfrog

	Years			
Industries	**1750–1900**	**1900–1950**	**1950–1975**	**1975–2000**
Shipping (steam)	83			
Shipping (steam motor)	180			
Rail (passenger)	126			
Rail (freight)	124			
Vehicles (private)	96			
Vehicles (commercial)	63			
Aviation (passenger)		60		
Aviation (freight)		60		
Telegram	91			
Telephone	99			
Radio		69		
Television		59		
Cable television		50		
Personal computers			24	
Internet use			23	
CAT scan			18	
Mobile phone				16

Data sources: World Bank, 2008; Comin and Hobijn, 2004.

Table 3: Some African solar projects and panel manufacturers

Name	**Country**	**Panel technology**	**Power range (Wp)**
Micro Care	South Africa	Polycrystalline	75–280
MLT Drives	South Africa	Monocrystalline, polycrystalline	
Rentech	South Africa	Polycrystalline	10–30
Karshi Solar Panel Plant-NASENI	Nigeria	Production of solar cells and panels from imported silicon wafers and solar cells	7.5MW panel
The Nzema project	Ghana	Concentrated solar power	155 megawatt plant
Ubbink East Africa – a joint venture between the Dutch Ubbink and Kenya’s Chloride Exide	Kenya	Production of solar cells and panels import broken solar cells mainly from the Netherlands and then reworked into smaller units.	
Setsolar	South Africa	Polycrystalline	25–280
Solairedirect Technologies	South Africa	Polycrystalline	70–250
Standby Power Technologies	Kenya	Monocrystalline, polycrystalline	12–160

Sources: NASENI 2012; ENF, 2013; Eveleens, 2011

Table 2: Summary of solar PV market in Africa

Countries	**South Africa**	**Nigeria**	**Ghana**	**Kenya**
PV capacity[i]	21 GWh	<1 MWp	0.55 MWp	7.05 MWp
Solar systems installed	150,000 installations Installed capacities of solar PV systems around 11,000 kWp.	Renewable energy targets of 16 GW by 2015. 1.938 GW total installed renewable electricity capacity, 2007.	4,500 solar systems in over 89 communities.	Between 200,000 and 350,000 solar PV home systems. Capacities of 4 MW and produce 9 GWh-
Key targets	• Generate 14% electricity from Solar PV by 2050. • Develop 8,400 MW of solar PV energy by 2030.	• 18% of electricity production by renewables 2025 and 20% by 2030. • Renewables will account for 7.0% of electricity by 2025.	• Boost renewable energy capacity from 1% in 2012 to 10% by 2020.	• Capacity building of local firms for domestic and export market by 2024. • Home solar systems are projected to generate 22 GWh annually by 2020.
Some key projects – Solar Flagships Programme	• Solar Energy Park in the Northern Cape Province combines both the PV and CSP technologies run by WBHO-Building Energy Ltd. • Contract with JinkoSolar Holding Co. Ltd to deliver 81 MW of PV modules to WBHO-Building Energy Ltd.	• HQMC Korea's investment project. • The Bishop Kodji project was financed through $272 million from the Rural Electrification Fund.	• Off-grid solar projects to electrify 24 rural communities supported by the Spanish Government and the Danish International Development Agency. • Renewable projects in East Mamprusi district and Tenzu.	• China Jiangxi Corporation for International Economic & Technical Co, Ltd. to build 50MW solar power project in Kenya.
Incentives to promote renewable energy.	• Renewable Energy Programme to install around 8 GW of PV power generations by 2030. • Government incentives such as	• Feed-in tariffs for renewables to support off-grid power generation. • NGOs funding.	• Institutional support for large-scale production such as government tax incentives for production and investments such	• Government policy framework – Private–public partnership for additional power generation. • Value added tax on solar panels was

	renewable energy such as tax credit, feed-in tariffs, capital subsidies and grants for power generation.	• Fiscal incentives such as tax credits and energy loan portfolio to support investments. • Economic Community of West African States' (ECOWAS) ECREEE programme.	as feed-in tariffs. • The Renewable Energy Law 2011 targets the installation of 15,000 solar systems in rural areas by 2013. • NGOs funding- • ECOWAS' ECREEE programme.	removed in 2007. • Feed-in tariff and mandate the use of solar power in new-build homes.
Barriers to scaling up: Similarities and differences	• High up-front capital costs of solar PV systems and inadequate end-user financing schemes. • Subsidised solar panels from China, the US and European countries such as Germany, Spain and Italy. • Lack of precision and long payback period for solar panels and return on investment.			
	• Domestic production faces intense competition from imports largely from China. • Wage increases and skill shortages • Obstacles to overcome include resistance from coal producers.	• Corruption, mismanagement and white elephant projects. • Inadequate public and policymakers' awareness of the benefits of solar energy. • Limited ability to absorb imported technologies. • Lack of strong policy frameworks to protect the foreign investors.	• Limited access to and slow adoption of solar technology. • Absence of clear regulatory framework. • Inadequate public and policymakers' awareness to the benefits of solar energy. • Limited attempts to leverage the import technologies. • Under-developed solar panel manufacturing sector.	• Low R&D intensity and tax incentives to manufacturers of renewable energy technologies to create domestic jobs.

Data sources: synthesized by the authors from: ECG, 2009; IEA, 2009; KPMG, 2012; Edkins et al., 2010a, b; Hankins, 2011; World Bank, 2008; UNIDO, 2009; UNIDO/REEEP, 2004; Kenya Ministry of Energy, 2004; Disenyana, 2009; ECREEE, 2010.

[ii] Based on 2009 data