

## Executive Summary

- **Energy poverty is a critical issue:** Of the world's 7 billion people, more than 1.2 billion (250-300 million households) currently lack access to electricity<sup>1</sup>; hundreds of millions more contend with power supplies that are low-quality or very unreliable. Such electricity deficits impede both human development and broader economic growth. Recognizing this, governments, companies, and civil society have in recent years launched major initiatives to tackle "energy poverty," with the United Nations declaring 2014-2024 the decade of "sustainable energy for all."
- **Coal as the solution for energy access?:** One constituency that has taken a particular interest in the energy poverty issue is the coal industry. Citing the increase in coal consumption that has accompanied urbanization and industrialization in multiple countries, industry advocates champion coal as the "only affordable fuel, at scale, to meet rising energy demands" and "essential to meet the scale of Africa's desperate need for electricity." Yet only 7% of those without access to energy in Sub-Saharan Africa live in the handful of countries with producing coal assets.
- **Realities of energy access - rural areas and grid extension costs limit contribution from coal:** In certain urban regions, the low-cost option to provide electricity access may involve coal-fired electricity delivered via a centralized grid. Globally, however, coal's contribution to extending energy access is constrained by the reality that: (1) 84% of individuals without electricity live in rural areas; (2) such areas often lack connections to a centralized electricity grid; and (3) the costs of grid extension plus grid-based electricity often exceed the costs of off-grid solutions such as diesel generators or small-scale wind, hydro, and solar PV. For the early stages of energy access (e.g. task lighting through to low-power appliances), technologies such as solar lanterns and mobile phone chargers can provide energy services for 4-20% of the cost of a grid connection.

<sup>1</sup> The International Energy Agency (IEA) defines initial "access" as annual electricity consumption of 250 kilowatt hours (kWh) for rural households and 500 kWh for urban households. For reference, in 2012 world average annual electricity consumption was 4000 kWh, while average annual European electricity consumption was 6000 kWh and average annual US electricity consumption was nearly 14000 kWh.

## Coal-fired energy for all? Examining coal's role in the energy development of India and sub-Saharan Africa

Focusing on India and sub-Saharan Africa, we examine solutions to make electricity more accessible, reliable, and affordable - particularly in respect of the role claimed for coal. Key takeaways are as follows:

- For initial stages of energy access (i.e. general lighting), off-grid interventions (e.g. solar lanterns) can provide energy access at 4-20% of the cost of grid extension
- In a scenario of universal electricity access by 2030, the IEA estimates 3/5 of households gaining access will do so via mini/off-grid solutions - in which coal plays little role
- Business model innovations such as pay-as-you-go financing and local manufacturing are essential
- High economic losses from unreliable grid-based power supplies make businesses a key early adopter of solar PV and other distributed generation - particularly with payback periods now at 4-6 years in many areas
- Declining battery costs are set to improve the economics of hybrid PV/diesel/battery systems by enabling greater reliance on solar output and less reliance on diesel
- India and Africa can achieve high (~80%) renewable electricity futures with minimal long-term impact on system costs or potentially savings – but up front capital costs are a challenge.

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- Progress on energy access offers limited upside to coal:** The coal industry regularly cites the IEA New Policies Scenario as driving huge growth in demand, and solving energy access problems. However this scenario only sees an 18% global increase in coal demand, and leaves nearly three-quarters of the energy poor still without access to energy. More relevant is the IEA's Energy for All scenario which does aim to provide universal access to energy by 2030. Relative to a base case where in 2030 969 million people still remain without access to electricity, the International Energy Agency (IEA) projects that achieving universal electricity will increase 2030 electricity demand by roughly 1400 terawatt-hours (TWh), or by 4.1% above the base case level. Owing partly to the grid extension costs noted above, only 35% of this additional 1400 TWh (i.e. 488 TWh) will come from fossil fuels, with the remainder coming from renewable generation sources such as hydro, wind, and solar. Pro-rating this incremental fossil fuel demand to coal, 215 TWh is equal to only 1.8% of global electricity generation from coal in 2011. This amount of extra generation could be offset by India and Sub-Saharan Africa reducing distribution losses by one third. We also expect further improvements in energy efficiency to erode demand for coal. *At least through 2030, it is therefore inappropriate to suggest that achieving universal electricity access will require a substantial increase in demand for coal-fired electricity.*
- Even with sufficient grid infrastructure, economic advantages of coal are dissipating...:** A more realistic source of growth in future coal demand results from the economic imperative for countries in Asia and sub-Saharan Africa to provide cities and businesses with reliable and affordable power. Even within this grid-connected market, however, there are barriers to coal serving as the "base fuel for power and steel to urbanize a world of over 9 billion people by 2050."<sup>2</sup> The cost of electricity from major new coal-fired projects in developing countries is often turning out to be much higher than expected. As a result of delays and cost overruns during construction, electricity from South African utility Eskom's massive new 4.8 GW Medupi plant is estimated to cost ~\$90/MWh. By way of comparison, in May 2013 Eskom contracted for 787 MW of wind power at an average cost of \$75/MWh and 435 MW of solar PV at an average cost of \$100/MWh. In India, comparing the costs for generating electricity from imported coal versus the cost of power from recent wind and solar PV projects tells a similar story. Though there is limited usefulness in such comparisons (as they exclude, for example, systems costs associated with variable wind and solar output), they do reveal how the rapid declines in the cost of renewable generating technologies is eroding the economic rationale for developing countries to invest in new coal-fired plants.

<sup>2</sup> Boyce, 2014: Peabody Energy, *21st Century Coal: Energy Access, Clean Coal Technologies and Sustainable Mining*, Presentation to Expert Group: Norwegian Government Pension Fund Global, June 2014,

- **... while environmental impacts and financing challenges remain:** Even where coal appears to offer the lowest-cost electricity, the attendant environmental impacts of coal-fired generation cannot be ignored. In addition to carbon-dioxide emissions, burning coal emits particulate matter emissions that are linked to increased prevalence of asthma and bronchitis, as well as an increase in the death rate from cardiovascular disease and respiratory ailments.<sup>3</sup> A recent air-sampling study, found PM2.5<sup>4</sup> levels in New Delhi to be twice as high as those in Beijing (and trending upward);<sup>5</sup> note that this is in a country that already has the world's highest death rate from chronic respiratory diseases and more deaths from asthma than any other nation.<sup>6</sup> More generally, a more recent analysis by Yale University researchers identified seven of the 10 countries with the worst air pollution exposures in the world to be in South Asia.<sup>7</sup> Though use of more advanced coal generation technologies can mitigate such air pollutants, they exacerbate a second challenge related to coal-fired generation in developing countries: financing. With the cost of a 1 GW subcritical (i.e. least-advanced) coal-fired power plant already exceeding \$1 billion, most developing nations are unable to afford such large investments. Even where the cost of electricity appears higher on a per-kWh basis, the smaller, modular nature of distributed renewable generation technologies is often a better financial fit for developing countries than are coal-fired plants.
- **Developing nations, including India and many in Africa, investing heavily in renewables:** Developing countries are investing heavily in renewable electricity. A recent survey of 55 emerging economies found that from 2007-2013 annual renewable investment in these countries more than doubled from \$59.3 billion to \$122 billion; as a result, over this period these countries installed a combined 142 GW of renewable generating capacity.<sup>8</sup> We note in particular recent advances in India and sub-Saharan Africa. Since 2006 India has added 25 GW of wind, solar, and bioenergy, with a goal of 72 GW by 2022.<sup>9</sup> *Momentum for renewable generation on the subcontinent is such that Coal India (one of the world's largest coal mining companies) is evaluating the possibility to invest \$1.2 billion in the development of 1000 MW of solar power plants.*<sup>10</sup> Meanwhile, led by countries such as South Africa, Kenya, Ethiopia, and Uganda, sub-Saharan Africa has seen a surge of investment into wind,

<sup>3</sup> US EPA, "PM 2.5: Objectives and History," <http://www.epa.gov/region4/sesd/pm25/p2.html>

<sup>4</sup> This refers to particulate matter less than 2.5 micrometers in diameter, which is believed to pose the greatest health risk because it penetrates deeply into lungs.

<sup>5</sup> Gardiner Harris, "Beijing's Bad Air Would be Step up for Smoggy Delhi," New York Times, Jan 25, 2014, [http://www.nytimes.com/2014/01/26/world/asia/beijings-air-would-be-step-up-for-smoggy-delhi.html?\\_r=0](http://www.nytimes.com/2014/01/26/world/asia/beijings-air-would-be-step-up-for-smoggy-delhi.html?_r=0)

<sup>6</sup> World Health Organization, "Mortality: Chronic respiratory diseases, deaths per 100,000 – Data by Country," <http://apps.who.int/gho/data/node.main.A866?lang=en>

<sup>7</sup> Yale Center for Law and Environmental Policy, "2014 Environmental Performance Index: Air Quality," <http://www.epi.yale.edu/our-methods/air-quality>

<sup>8</sup> By way of comparison, as of 2011 global renewable generating capacity, excluding hydropower, was 413 GW.

<sup>9</sup> By way of comparison, India's 2011 total installed generating capacity - across all fuel types - was 215 GW).

<sup>10</sup> Mridul Chadha, "World's Largest Coal Miner to Invest \$1.2 billion in Solar," *CleanTechnica*, Sep 24 2014, <http://cleantechnica.com/2014/09/24/worlds-largest-coal-miner-invest-1-2-billion-solar-power/>

solar, hydropower, and geothermal projects. Since 2010 cumulative installed solar capacity has increased from 40 MW to 280 MW, with 150 MW+ of grid-connected projects now under construction in South Africa and Ghana, with proposals for ~100 MW projects in Ethiopia, Nigeria, Sudan, and Mozambique.

- Business model innovations accelerating clean energy deployment in developing countries:** For all of the focus on declining technology costs, we highlight how innovations in manufacturing, financing, and operations are accelerating adoption of renewable technologies in developing countries. Pay-as-you-go financing models are reducing the upfront cost of solar for both isolated, off-grid villages and grid-connected commercial enterprises. Development of local solar manufacturing capacity is overcoming the obstacle of import tariffs and increasing local job-creation from clean energy. And entrepreneurs are leveraging the spare power capacity of 600,000 off-grid cell phone towers to distribute electricity to areas not yet connected to a centralized grid. Combined with lower technology costs, such innovations are making renewable electricity sources increasingly competitive with centralized, fossil-fuelled generation and we expect this trend to continue.
- Recent deployments highlight potential renewable future for India and Africa:** Rising deployment of renewable electricity sources in recent years increases the relevance of scenarios in which India and Africa move toward futures dominated by renewable, low-carbon electricity. In the IEA's 2°C high-Renewables Scenario (hi-Ren Scenario), for example, by 2050 both of these regions generate more than 80% of their electricity from low-carbon renewable sources<sup>11</sup> (versus roughly 17% in 2011) and less than 5% from coal (versus, in 2011, 68% for India and 38% for Africa). Whereas in 2011 solar power accounted for less than 1% of total electricity generation in both India and Africa, in the IEA's hi-Ren Scenario by 2050 these shares rise to roughly 40%.
- Renewable future requires upfront investment, but over the long term higher costs are offset by fuel savings:** Such a sustained scaling up of renewable generation will require substantial investment in order to occur. Relative to extending current power-sector investment trends through 2050, a hi-Ren scenario will require average annual investment to increase by \$45 billion (i.e. 71%) in India and by \$20 billion (i.e. 50%) in Africa. *Accounting for trillions in cumulative fuel savings as a result of burning less coal/oil/gas, however, over the long such investments are likely to increase total costs for power generation in these regions by at most 1%. Given our view of improving economics for renewables we can see this becoming a net positive. And there should be an increasing move to local manufacturing.* Compared with 2013 annual per-capita GDP levels, required average annual additional investments

<sup>11</sup> These include solar photovoltaic technologies (solar PV), concentrating solar power (CSP), wind, hydropower, biomass, geothermal, and marine power.

for a hi-Ren Scenario amount to 2.5% of per-capita GDP in India and 0.1-6.0% of per-capita GDP levels in Africa. For comparison, as a result of limited access to modern energy sources, households in these countries currently spend anywhere from 6-14% of household income on energy. That said, this additional required investment highlights the importance of initiatives to accelerate flows of clean energy finance into developing countries, such as the commitment of \$100 billion by 2020 that developed countries made as part of the 2010 Cancun Agreements.

- Unreliable and costly power supplies have led Indian and African business to invest heavily in on-site generation....:** Power outages cause businesses to lose, on average, 7% of their working hours in South Asia and 13% in Africa; annual economic losses as a result of these disruptions average \$12000 per firm in South Asia and \$9000 per firm in Africa. In Africa, even when grid-based electricity is available, commercial and industrial businesses pay among the highest electricity tariffs in the world. In response to unreliable and costly power supplies, businesses in these regions have invested heavily in on-site generation, typically in the form of diesel generators with capacities ranging from 1-5 MW (for small and medium-sized firms) and up to several hundred MW for large firms. On-site diesel generators, however, carry a high cost, with the levelized cost of electricity (LCOE) from such systems often exceeding \$300/MWh and (in areas with particular high diesel costs) at times reaching \$500/MWh or more.
- ... creating a tremendous economic opportunity for distributed clean generation - in particular hybrid PV/diesel systems with batteries:** This creates a tremendous economic opportunity for distributed renewable generation technologies such as solar PV. In East Africa, for example, we estimate that the simple payback for investment in distributed solar PV systems can be as low as 6 years (against grid-based electricity) or as low as 4 years (against diesel). Distributed PV will often be deployed as part of hybrid PV/diesel system, with PV output being used to meet midday loads and diesel generation (or stored solar electricity) being used to cover early morning or nighttime loads.
- Declining battery costs will enable hybrid systems to use more solar and less diesel:** Including battery storage in hybrid PV/diesel systems enables a greater portion of load to be met through solar power, reducing reliance on costly diesel generation. Current battery prices, however, often constrain the amount of storage capacity that it is economical for hybrid diesel/PV systems to employ. For example, in the case of a 300 kW system, each MWh charged via battery typically adds \$200/MWh or more in cost - making battery costs 30% or more of the LCOE of such a system. As a result, assuming a diesel price of \$1/liter, the LCOE of PV/diesel-battery hybrid systems ranges from roughly

\$270/MWh (for a 1 MW system) to over \$450/MWh (for a 300 kW system).<sup>12</sup> Though generally still less expensive than diesel generation, the difference has heretofore been too small to motivate widespread adoption. *Projected declines in battery costs, however, are set to make the economics of PV/diesel-battery hybrid systems more attractive.* For example, the Tesla Motors "Gigafactory" is currently sourcing lithium-ion batteries from Panasonic at a price (\$168/MWh) that is 40% less than the per-MWh price of batteries in most hybrid storage systems; moreover, based on material costs, the long-term competitive price for lithium-ion batteries may be as low as \$100/MWh. Other battery chemistries have similarly attractive long-term economics. Battery costs at \$100/MWh could reduce the LCOE of a 300 kW hybrid system by 20% or more - resulting in greater savings relative to diesel generation, faster paybacks of up-front investment, and broader adoption.

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<sup>12</sup> Very small systems, on the order of 10 kW, can have costs as high as \$600/MWh.

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## Section One: Background on energy poverty, economic growth, and coal

Of the world's 7 billion people, more than 1.2 billion currently lack access to electricity, with hundreds of millions more contending with unreliable or low-quality power supplies.<sup>13</sup> For these 250-300 million households - 95% of whom are in sub-Saharan Africa or developing Asia - lack of electricity access impedes progress toward a better quality of life. The Global Commission on the Economy and Climate recently noted that:

*"access to electricity allows households to have more productive hours, including time for children to study; with moderate rises in income, it also provides access to welfare-and productivity-enhancing electronics such as mobile telephones and refrigeration. Reliable electricity access also improves business productivity, and provides access to telecommunications, which can facilitate growth in a range of development areas such as health care, institutional access, and political voice."*<sup>14</sup>

*"As a result of reduced cash expenditures on kerosene and diesel, longer school hours for children, and healthier indoor and outdoor environments, electricity access is estimated to account for "38% of the increase in the Human Development Index needed to move from current poverty levels towards significant poverty reduction by 2030."*<sup>15</sup>

Most discussions of "energy poverty" focus, understandably, on the issue of "energy access," as detailed in Appendix A. As financial analysts we are best placed to comment on the economics of different energy options, although recognize that there are other issues such as the wider development and environmental impacts of coal – not least climate change. This analysis therefore focuses primarily on two of the economic development issues, although it is impossible to separate the different aspects of tackling poverty:

1. **Energy access:** International Energy Agency (IEA) defines initial "access" as annual electricity consumption of 250 kilowatt hours (kWh) for rural households and 500 kWh for urban households.<sup>16</sup> For reference, in 2012 world average annual electricity consumption was 4000 kWh, while average annual European electricity consumption was 6000 kWh and average annual US electricity consumption was nearly 14000 kWh.<sup>17</sup>
2. **Energy as an input to economic growth:** Energy needed to support economic growth in developing countries, and in particular the expansion of small and medium-sized businesses. Note that this second dimension involves attributes of the energy supply - i.e. quality, reliability, affordability - in addition to the issue of access.

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<sup>13</sup> International Energy Agency (IEA), *World Energy Outlook (WEO) 2013 Electricity Database*, "Table 1 - Electricity access in 2011 - Regional aggregates," Nov 2013.

<sup>14</sup> The Global Commission on the Economy and Climate, *BETTER GROWTH, BETTER CLIMATE: THE NEW CLIMATE ECONOMY REPORT*, "Chapter 4: Energy," Sep 2014, 19.

<sup>15</sup> Clean Energy for All Stewart Craine, Evan Mills, and Justin Guay, "Clean Energy Services for All: Financing Universal Electrification," June 2014, 3.

<sup>16</sup> <http://www.worldenergyoutlook.org/resources/energydevelopment/definingandmodellingenergyaccess/>.  
[http://www.worldenergyoutlook.org/media/weowebiste/energymodel/documentation/EnergyAccess\\_Methodology\\_2012\\_FINAL.pdf](http://www.worldenergyoutlook.org/media/weowebiste/energymodel/documentation/EnergyAccess_Methodology_2012_FINAL.pdf)

<sup>17</sup> <http://data.worldbank.org/indicator/EG.USE.ELEC.KH>



This approach reflects that alongside the fundamental issue of improving energy access, it is important to recognize in the longer term this leads to opportunities for economic development and the building of an economy. Indeed the IEA in its energy scenarios look at the whole of a developing economy, not just energy access. This encompasses urbanization, but crucially the development of local enterprises, who will need energy to move ahead. These enterprises are also quite likely to be closer to cities. As we look at solutions to energy poverty then these must ultimately be applicable in this broader context.

### ***The geography of energy access***

The figures on energy access indicate a stark distinction between rural and urban poverty levels. It is clear from the data in Table 1 that the main challenge lies in rural areas, with only 18% of the rural population in Sub-Saharan Africa having access to electricity, compared to 55% in urban areas. India sees a higher rate of 67% in rural areas, but this still compares poorly to 94% of the urban population. Between them, India and Sub-Saharan Africa account for 72% of the global population without electricity; which is why they are the main focus regions of this study.

**Table 1: Electricity access in 2011 - Regional aggregates**

Region	Population without electricity millions	Electrification rate %	Urban electrification rate %	Rural electrification rate %
<b>Developing countries</b>	<b>1,257</b>	<b>76.5</b>	<b>90.6</b>	<b>65.1</b>
Africa	600	43	65	28
<i>North Africa</i>	<i>1</i>	<i>99</i>	<i>100</i>	<i>99</i>
<i>Sub-Saharan Africa</i>	<i>599</i>	<i>32</i>	<i>55</i>	<i>18</i>
Developing Asia	615	83	95	75
<i>India</i>	<i>306</i>	<i>75</i>	<i>94</i>	<i>67</i>
<i>Rest of developing Asia</i>	<i>309</i>	<i>87</i>	<i>95</i>	<i>80</i>
Latin America	24	95	99	81
Middle East	19	91	99	76
<b>Transition economies &amp; OECD</b>	<b>1</b>	<b>99.9</b>	<b>100.0</b>	<b>99.7</b>
<b>World</b>	<b>1,258</b>	<b>81.9</b>	<b>93.7</b>	<b>69.0</b>

*Note: The IEA defines initial "access" to electricity as annual consumption of 250 kWh in rural areas and 500 kWh in urban areas.*

*Source: IEA, World Energy Outlook*

**Conclusion: Though inadequate electricity access anywhere is a pressing issue, the problem is primarily a *rural* one – with electrification levels being much lower in rural areas than in urban areas in the developing world.**

### ***Recent focus on energy access***

The manifold benefits of reliable access to electricity have supported a groundswell of activity around achieving the goal of universal electrification. In 2011, the United Nations (UN) General Assembly declared 2012 to be the "International Year of Sustainable Energy for All", with the General Assembly subsequently declaring 2014-2024 the "Decade of Sustainable Energy for All." Concurrently, 70 countries have formally embraced the UN-backed Sustainable Energy for All (SE4ALL) initiative, which aims - among other goals - to achieve universal electrification by 2030 (versus an 83% global electrification rate in 2010).<sup>18</sup> Private companies and government agencies from around the world have already committed tens of billions of dollars to achieving the SE4ALL objectives. At the same time, achievement of universal access to electricity - with "access" usually being defined as energy services sufficient to support general lighting, fans, and television equipment - is regarded as just one step in the path toward developing the stable power supplies that emerging economies throughout the world will need for continued economic expansion over the coming decades.

### ***Energy-poor countries have significant exposure to impacts from climate change***

Focus on the issue of electricity access has stoked discussion of the role of fossil fuels - and coal in particular - in supporting the pursuit of universal electricity access. The urgency of this discussion results in part from countries with the largest electricity deficits - chiefly in sub-Saharan Africa and developing Asia - also being among the most vulnerable to adverse impacts of climate change such as reduced crop productivity and drought-related food and water shortages. This has long been recognized the OECD and other organizations considering the need for adaptation and mitigation in the developing world.<sup>19</sup>

The UN IPCC's WGII report on the impacts, adaptation and vulnerabilities related to climate change, concluded that the negative impacts on crop yields have been more common than positive impacts.<sup>20</sup> This finding refers mainly to reduced crop production rather than access, meaning that those poor countries in warmer and drier regions of the Earth will see crop yields fall, and prices rise, soonest. As well as from a changing climate, crop yields are also under pressure from air pollution, to which coal burning is a significant contributor. A study from November 2014 found that pollution in India was already so severe that yields of wheat and rice are being cut by almost half.<sup>21</sup>

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<sup>18</sup> Sustainable Energy for All (SE4ALL), *Global Tracking Framework*, 2013, 10. In addition to achieving "universal access to modern energy services," the two other SE4ALL objectives are to double rate of improvement of energy efficiency and double the share of renewable energy in the global energy mix. For details on the SE4ALL criteria for energy access, see Appendix A.

<sup>19</sup> OECD, 2003: Poverty and Climate Change, <http://www.oecd.org/env/cc/2502872.pdf>

<sup>20</sup> IPCC, 2014: Summary for policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

<sup>21</sup> Azeen Ghorayshi, 'India air pollution 'cutting crop yields by almost half' 3 November 2014, <http://www.theguardian.com/environment/2014/nov/03/india-air-pollution-cutting-crop-yields-by-almost-half>

As a major exporter of rice, this poses a threat to global food security. The World Bank found that in a warming world food security will be most pressing in sub-Saharan Africa. In this region, drought and aridity consistent with 1.5°C-2°C of warming will contribute to farmers losing 40-80% of cropland by the 2030s-2040s.<sup>22</sup>

Furthermore, the number of natural disasters between 2000 and 2009 was approximately three times higher than in the 1980s.<sup>23</sup> This will continue to hit the most impoverished regions of the world. For example, the IPCC predicts east Africa to experience increased short rains, while West Africa can expect stronger cyclones.<sup>24</sup> Due to a lower capacity to prepare, protect and recover from natural disasters in poorer countries, the same strength hazard has a larger impact than in richer nations.

Food production and weather-related extremes are just two factors amid numerous aspects of climate change predicted to disproportionately affect the poor. The cumulative effect of these impacts on poor nations, concluded the IPCC, is that climate change will make it harder for developing countries to climb out of poverty, instead creating what are termed 'poverty pockets' within these nations.<sup>25</sup> The IEA NPS used as the reference case by the fossil fuel industry to justify future demand levels is equivalent to 3.6°C of warming, and therefore would result in significant impacts for the developing world.

**Conclusion: There is a fundamental contradiction in promoting fossil fuels as the solution which will improve development outcomes, given the negative impacts that will result from exacerbating climate change.**

### ***Will developing economies follow the same fossil fuel pathway?***

Over the past century, the chief inputs to a widely available electricity supply have usually been: (1) large, centralized generation plants burning coal, oil, or natural gas; and (2) electricity delivered via transmission and distribution networks to which all households are connected. The first condition supporting this centralized, grid-based approach to delivering electricity has been the concentration of populations in cities (which minimizes the cost of grid extension). As a result, closure of electricity deficits has often resulted in significant increases in coal consumption. For example, over the past several decades, coal has figured prominently in the electrification successes of China, Thailand, and

<sup>22</sup> World Bank, 'What climate change means for Africa, Asia and the Coastal Poor' 19 June 2014, <http://www.worldbank.org/en/news/feature/2013/06/19/what-climate-change-means-africa-asia-coastal-poor>

<sup>23</sup> Suzanne Goldenberg, 'Climate change: the poor will suffer most' 31 March 2014,

<http://www.theguardian.com/environment/2014/mar/31/climate-change-poor-suffer-most-un-report>

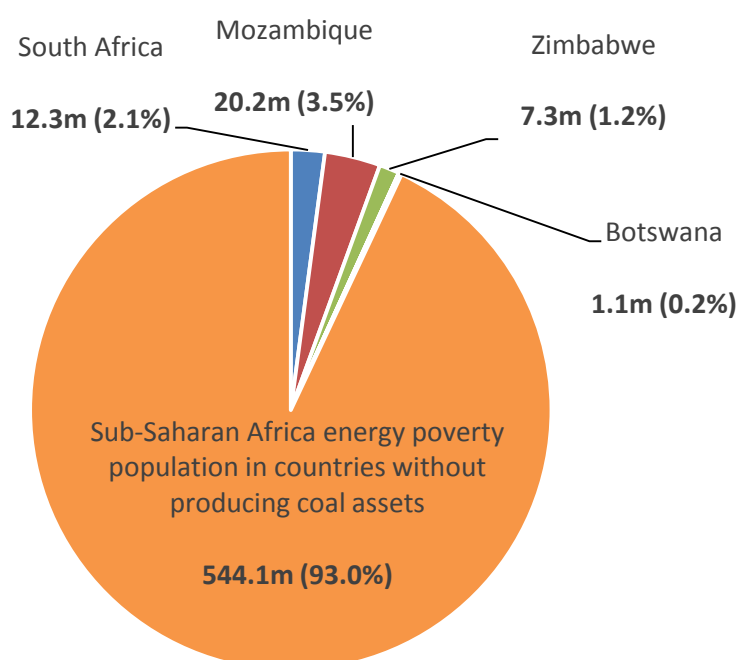
<sup>24</sup> IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

<sup>25</sup> IPCC, 2014: Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

Vietnam. The second condition is having access to cheap plentiful sources of coal has certainly been a major element of economic growth in a number of countries with significant reserves in the past. However this is no guarantee that other countries will follow suit, especially if they don't have any reserves.

Firstly many of the countries affected by energy access challenges do not have coal reserves. Currently in Sub-Saharan Africa, only four countries are producing coal – South Africa, Botswana, Mozambique and Zimbabwe – with only South Africa contributing at any scale. Coal options are therefore concentrated in the very south of the continent. The challenges of producing coal in some of these countries have also become clearer, with Rio Tinto writing off \$3bn on a coal asset in Mozambique it bought and then sold in 2014.<sup>26</sup>

**Figure 1: Percentage of population without energy access in Sub-Saharan countries with producing coal assets**



Source: IEA World Energy Outlook 2013, RMG data, CTI analysis

The basic fact is that there are no coal reserves in the countries which are home to 93% of those without energy access in sub-Saharan Africa.<sup>27</sup> This means there is no domestic coal supply in those countries with some of the lowest percentages of total population with access to electricity, such as Uganda (15%), Tanzania (15%) and Kenya (19%).<sup>28</sup> Import costs of coal supply to these countries will make coal consumption less economic against alternatives. For those more northern African countries many of whom only have electricity access to approximately 50% of the population, e.g. Nigeria and Cameroon, this loss of competitiveness only heightens.

**Conclusion: Only 7% of the people in Sub-Saharan African countries who lack access to energy live in countries with coal assets.**

<sup>26</sup> <http://www.bloomberg.com/news/2014-07-30/rio-tinto-closes-book-on-mozambique-coal-with-50-million-sale.html>

<sup>27</sup> No data available for Swaziland

<sup>28</sup> World Bank, Access to Electricity (% of population), <http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS>

### ***Coal Industry highlighting coal as a solution to energy access***

Emphasizing: (1) the scale and urgency of the energy access problem; and (2) historic coal consumption trends in rapidly developing countries, the coal industry has begun to advocate coal as the indispensable fuel for achieving universal electricity access. For example, the Chairman and CEO of Peabody Energy recently pledged to "eliminate energy poverty as priority one," while also committing to "create energy access for all by 2050" and "advance all energy forms for long-term access."<sup>29</sup>

## INDUSTRY ARGUMENTS FOR COAL

As presented in materials such as documents from the "Advanced Energy for Life" campaign, industry arguments for coal's essential role in addressing energy poverty are straightforward:

- **Urbanization as the pathway to electricity access:** Coal companies emphasize that *urbanization* is the pathway to provide electricity access, noting that an additional 3 billion people will move into cities by 2050 (relative to the current global urban population of 3.5 billion).
- **Urbanization and economic development drive significant new demand for electricity:** Reviewing the correlation between urban growth and energy demand, Peabody Energy notes that from 1950-2010 the global urban population grew by 3 billion and global coal demand more than tripled (i.e. increased from 2 billion tonnes to 7.1 billion tonnes).
- **"Coal is the only affordable fuel, at scale, to meet rising energy demands":** Coal companies claim that a number of advantages- including low cost, energy density, ease of transport, wide availability, and integration into baseload generation capacity - make coal the "only affordable fuel, at scale, to meet rising energy demands." In the case of Africa, analyses cited by the coal industry specifically assert that "coal is essential to meet the scale of Africa's desperate need for electricity."<sup>1</sup>
- **"Clean coal technologies provide the method to address access as well as environmental concerns":** Advocates assert that technologies such as supercritical coal-fired plants and carbon capture and sequestration (CCS) will provide an affordable way to mitigate both the local and global environmental impacts of coal-fired generation.

<sup>29</sup> Boyce 2014 Peabody p. 18 Peabody Energy, *21st Century Coal: Energy Access, Clean Coal Technologies and Sustainable Mining*, Presentation to Expert Group: Norwegian Government Pension Fund Global, June 2014, slide 18.

### ***Rigorously evaluating the coal-energy access nexus***

As multiple analysts have noted<sup>30</sup>, the industry analysis outlined above suffers from serious omissions and simplifications. Pursuit of universal electricity access - and development of African and Asian economies more generally - will indeed create incremental sources of demand for coal. This incremental demand, however, is likely to be far lower than industry forecasts suggest.

The industry narrative overlooks that energy poverty is - and will remain - a largely *rural* phenomenon; in many rural areas, the most cost-effective means of energy access is not grid extension but rather mini-grid and off-grid solutions such as small-scale solar PV, wind, and hydropower. Moreover, even within the grid-connected market, rapid declines in the cost of renewable technologies and proliferation of new business models mean that the future will not look like the past. Even as the world adds 3.5 billion people to cities, those residents will be able to meet growing energy needs through a range of options far broader than the options available even a few decades ago.

The rest of this paper explores the latest thinking on energy futures focusing in particular on technologies and models for providing energy access in India and sub-Saharan Africa. For example, a recent IEA scenario for universal energy access by 2030 assumes 56% of the investment would go to “mini-grids” and off-grid solutions, with up to 90% using renewable energy sources. In principle, these technologies are a good fit because they are modular and can be installed at small scales. Inexpensive low-carbon solutions are also emerging to meet specific needs, such as solar mobile-phone chargers and rooftop solar water heaters. Further, the distribution cost of access via grid expansion will be high in many cases. Distributed generation technologies can often provide electricity more cost-effectively in these cases, though care should be taken to ensure that the technologies employed do not imply a lock-in to perpetually low-power electricity consumption.

### ***Are alternatives to coal too expensive?***

Many commentators who advocate coal as a solution to energy poverty are particularly critical of renewable energy sources. One commentator, for example, notes that: (1) from 2002-2002, non-carbon sources (including hydropower) met just 14% of the overall increase in global primary energy demand (i.e. 350 and 2500 Mtoe); and (2) that “over the past 10 years the world invested more than \$600 billion in wind power and \$700 billion in solar power. Yet the total contribution those two technologies are now making to the world primary energy supply is still less than 2 per cent.”<sup>31</sup> The conclusions often drawn from the above analysis are that (1) any serious effort to achieve universal electricity access must involve a significant contribution from coal; and (2) the push to achieve universal access - and develop emerging economies more generally - will underpin steadily growing coal demand over the coming decades.

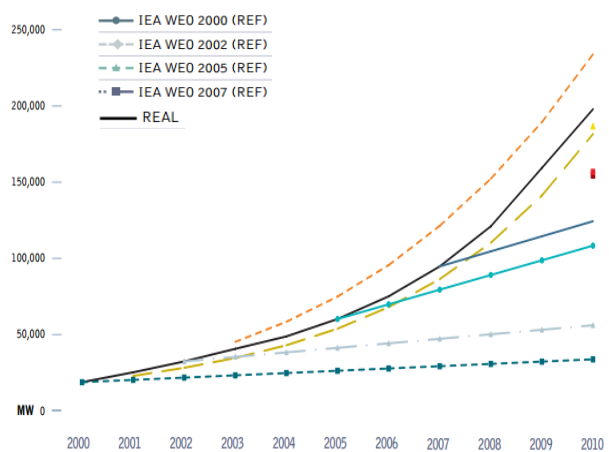
Coal will continue to play a role in the meetings the world’s energy needs for decades to come. That said, and recognizing the difficulties of projecting global energy trends, it is notable that over the past decade most analysts have consistently underestimated the growth of renewable energy deployment. For example, Figures 2 and 3 below show that even the IEA have repeatedly significantly underestimated the growth of solar and wind capacity additions.

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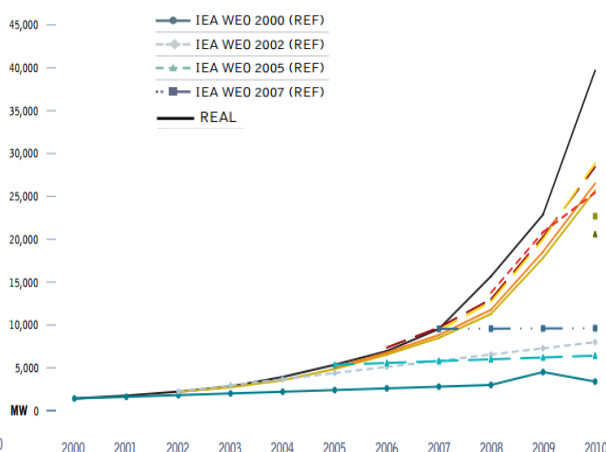
<sup>30</sup> Carl Pope, “Powering the World’s Poorest Economies: A Response to Bill Gates and Jigar Shah,” Aug 28 2014, *Greentech Media*, <http://www.greentechmedia.com/articles/read/Powering-the-Worlds-Poorer-Economies-A-Response-to-Bill-Gates-and-Jigar-S>

<sup>31</sup> Brendan Parson, “Coal delivers a clean future for the poor,” *Australian Financial Review*, Oct 5 2014 <http://www.afr.com/Page/Uuid/3031c45e-4ad2-11e4-887b-f62f9fb33d15>

**Figure 2: Wind power – IEA WEO forecasts vs real market development**



**Figure 3: Photovoltaics – IEA WEO forecasts vs real market Development**



Source: Greenpeace International, European Renewable Energy Council, Global Wind Energy Council, 2012<sup>32</sup>

**Conclusion: Deployment of both solar and wind has repeatedly beaten the forecasts of energy commentators since 2000. This suggests it is sensible to consider such a scenario going forward where expectations are again exceeded.**

<sup>32</sup> Greenpeace International, European Renewable Energy Council, Global Wind Energy Council, Energy [r]evolution: A sustainable world energy outlook, <http://www.greenpeace.org/international/Global/international/publications/climate/2012/Energy%20Revolution%202012/ER2012.pdf>



## OVERVIEW OF IEA SCENARIOS

A number of the IEA's scenarios are referenced in this report, each of which have different assumptions about the future dynamics between fossil fuel energy sources and low carbon renewable options, and the resulting impacts on global energy access and climate change. Only one IEA scenario models global universal access to electricity – the **Energy for All** scenario. This scenario finds:

- Global electricity demand increases by 1396TWh – 4.1% higher than the New Policies Scenario by 2030;
- To meet this demand, grid extension is assumed for all urban zones and 30% of rural areas; mini-grids or small, stand-alone off-grid solutions are most economical for the remaining rural areas because the combination of high direct costs and transmission losses make grid extension expensive;
- Additional demand results in higher CO<sub>2</sub> emissions, but less than might be expected due to low per capital energy consumption – by 2030, global CO<sub>2</sub> emissions are 0.7% higher than the New Policies scenario.

**New Policies Scenario (NPS):** The IEA's central scenario, the NPS is based on the continuation of existing policies and the cautious implementation of commitments and plans as announced by mid-2014 (in the Africa Energy Outlook report) or mid-2013 (if using the World Energy Outlook report). Globally this scenario takes the world on a trajectory consistent with a long-term average temperature increase of 3.6°C. By 2030 there remain 969 million people without access to electricity, including 645 million in sub-Saharan Africa (an increase on current levels) and 147 million in India (a reduction by half on present). Fossil fuel use expands but declines relatively.

No other IEA scenario referenced in this report indicates the outcomes in terms of energy access. Consequently, it must be assumed no other scenario achieves universal energy access. However, it could be inferred that those scenarios with higher renewable energy generation achieve higher energy access due to its suitability for bringing energy to those most remote, rural populations in energy poverty, as outline above. Overall CTI-ETA research in this report leads us to believe the deployment of distributed systems will prove greater and coal feature less.

**450 Scenario:** An energy pathway compatible with a 50% chance of limiting the long-term increase in average global temperature to 2°C presented in the World Energy Outlook reports. In this scenario, fossil fuels make up only 34% of global electricity generation in 2035.

**2DS:** Broadly consistent with the 450 scenario through to 2035, this scenario 'offers a vision of a sustainable energy system of reduced greenhouse gas and carbon dioxide emissions' in which fossil fuels make up 20% of electricity generation by 2050, most with CCS.

**2DS hi-Ren:** A variant of the 2DS which sees reduced deployment of CCS compared to the other 2°C scenarios, and so forecasts higher electricity generation from renewable energy sources in favour of fossil fuel alternatives. In this scenario by 2050 less than 5% of electricity generation is coming from coal in both India and Africa; more than 80% is coming from low carbon renewable sources.

**6DS:** Largely an extension of current trends, and broadly consistent with the IEA's Current Policies Scenario, energy use grows by more than two-thirds compared to 2011 levels and emissions rise in line with a long term average global temperature increase of 6°C with 'potentially devastating results'. This scenario doesn't achieve energy access for all as energy poverty is not fully tackled in rural areas. Fossil fuels are more dominant.

## Reality Check: IEA projections of coal use as a means to support economic development in India and Africa

Coal companies regularly cite IEA scenarios to justify coal as the solution to energy poverty.<sup>33</sup> These citations, however, tend to stress the macro-findings of the IEA's New Policies Scenario or Current Policies Scenario, rather than the specific "Energy for All" case, which looks specifically at the issue of energy access. As a first step to evaluating the role of coal in extending energy access and supporting economic development in India and Africa, it is therefore informative to examine the projections from the IEA. As noted above (and discussed below), however, IEA scenarios generally project total electricity demand and sources to meet that demand, rather than assuming the achievement of specific targets for meeting energy access.

We will focus initially on the New Policies Scenario (NPS), which is the IEA's central scenario. *In the New Policies Scenario through 2035, coal-fired electricity generation follows a similar pattern in India and Africa: increasing in absolute terms, but declining as a share of the overall generation mix.* The projected increase in coal-fired generation, however, is far steeper for India - *though, as discussed later in this paper, there are reasons to be skeptical that this increase will occur.*

- India adds 278 gigawatts (GW) of coal-fired electrical capacity and coal-fired electricity generation increases by 1178 terawatt-hours (TWh), reflecting a compound annual growth rate (CAGR) of 4%. Over this period, however, coal's share of India's overall electricity generation mix declines from 68% to 56%.
- Africa adds 48 GW of coal-fired electrical capacity and coal-fired electricity generation increases by 131 TWh, reflecting a CAGR of 1.7%.<sup>34</sup> Over this period, however, coal's share of Africa's overall electricity generation mix declines from 38% to 26%. Within Africa, there is regional variation, with coal increasing in some regions more than others. Two of Africa's regions see growth in coal's share of electricity generation between 2012 and 2035 in the IEA's New Policies Scenario; East Africa by 12% and West Africa by 8%. This is in large part because there was no coal capacity in these regions in 2012. Central Africa is another region that has no coal capacity in 2012 but under this scenario does not develop any by 2035. The largest decline in coal's share of electricity generation is forecasted to occur in Southern Africa where its share of the energy mix falls 27% over this period, driven in large part by a 31% decline seen in South Africa.
- Note that in the IEA's recent Africa Energy Outlook, within sub-Saharan Africa coal-fired generation grows at roughly the same CAGR (1.8%) as in Africa generally; that said, coal use as a share of the overall power mix falls even more sharply than in Africa generally, from 56% in 2012 to 30% in 2035.<sup>35</sup>

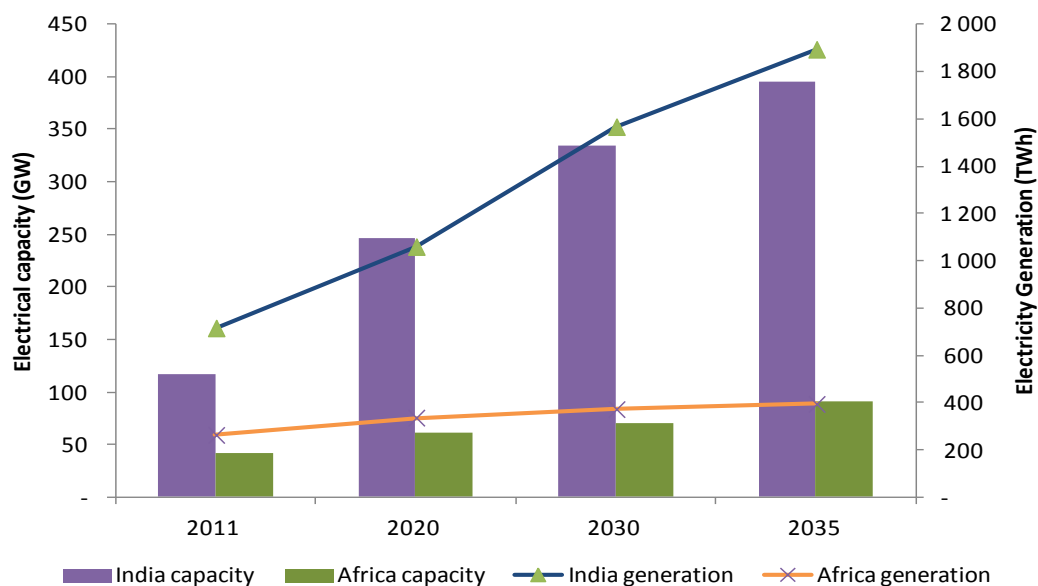
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<sup>33</sup> Peabody Energy, 8.

<sup>34</sup> Though not a focus of this paper, in the New Policies Scenario through 2035 trends for coal-fired capacity and generation in the other region with a significant concentration of energy poverty - which the IEA terms "developing Asia excluding India and China" - are different from those in India and Africa. Coal-fired electricity generation grows (at a 5.1% CAGR) but declines, and increases as a share of total generation from 31% to 41%.

<sup>35</sup> IEA, World Energy Outlook Special Report - Africa Energy Outlook: A Focus on Energy Prospects in sub-Saharan Africa, Oct 2014, 196.

Figure 4: India and Africa coal-fired electrical capacity and electricity generation in IEA New Policies Scenario, 2011-2035



Source: IEA, CTI/ETA analysis 2014

Figure 5: India electricity generation by fuel source in the New Policies Scenario, 2011 (left-hand side) vs. 2035 (right-hand side)

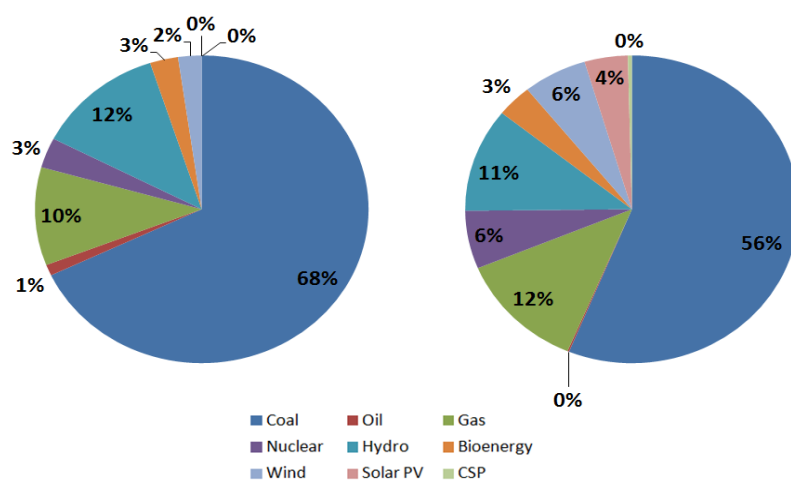


Figure 6: Africa electricity generation by fuel source in the New Policies Scenario, 2011 (left-hand side) vs. 2035 (right-hand side)

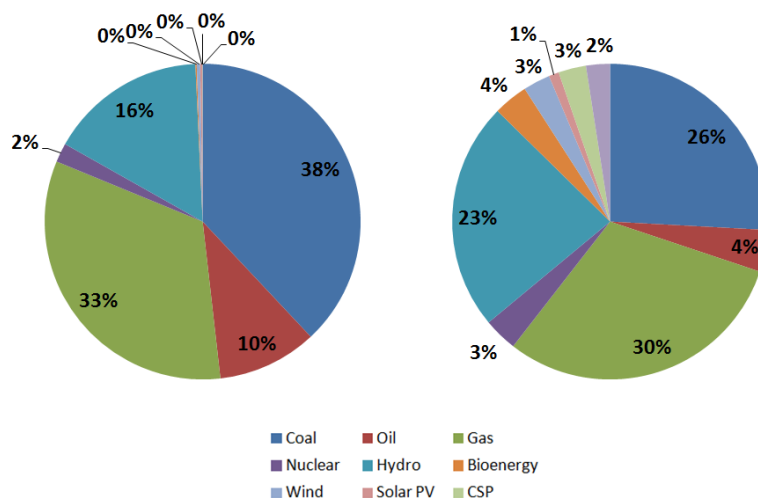
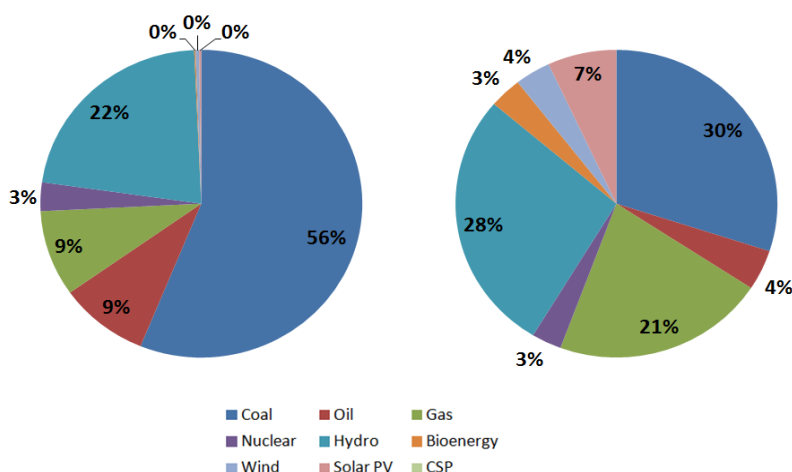


Figure 7: Sub-Saharan Africa electricity generation by fuel source in the New Policies Scenario, 2012 (left-hand side) vs. 2035 (right-hand side)



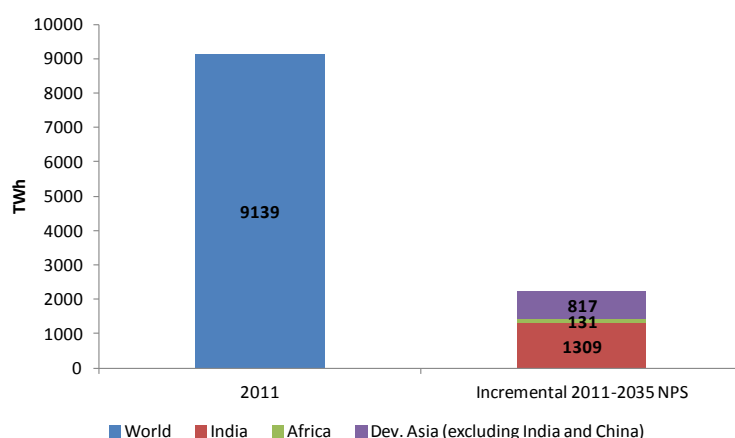
Source: IEA, CTI/ETA analysis 2014

This quick analysis of coal demand trends in the New Policies Scenario illustrates several important conclusions. Increasing consumption of coal-fired electricity in India and Africa underscores that - ignoring for the moment considerations related to carbon pollution - economic development in these regions is likely to result in increased coal consumption. That said, it is important to be precise about the magnitude of the potential increase in coal demand.

In the New Policies Scenario through 2035, incremental coal-fired electricity generation in India and Africa amounts to 2126 TWh, an amount equal to 14% of global coal-fired electricity generation in 2011<sup>36</sup>; adding in other developing Asian countries (excluding China) and the amount rises to 2257 TWh, an amount equal to 23% of global coal-fired electricity generation in 2011. *Should these projections be borne out, this would represent a material source of new coal demand. It would, however, be far from the "tripling of global coal demand" that occurred from 1950-2001, and that is a staple of the coal industry discussions of future energy demand in emerging economies.*

<sup>36</sup> IEA, *World Energy Outlook 2013*, 574.

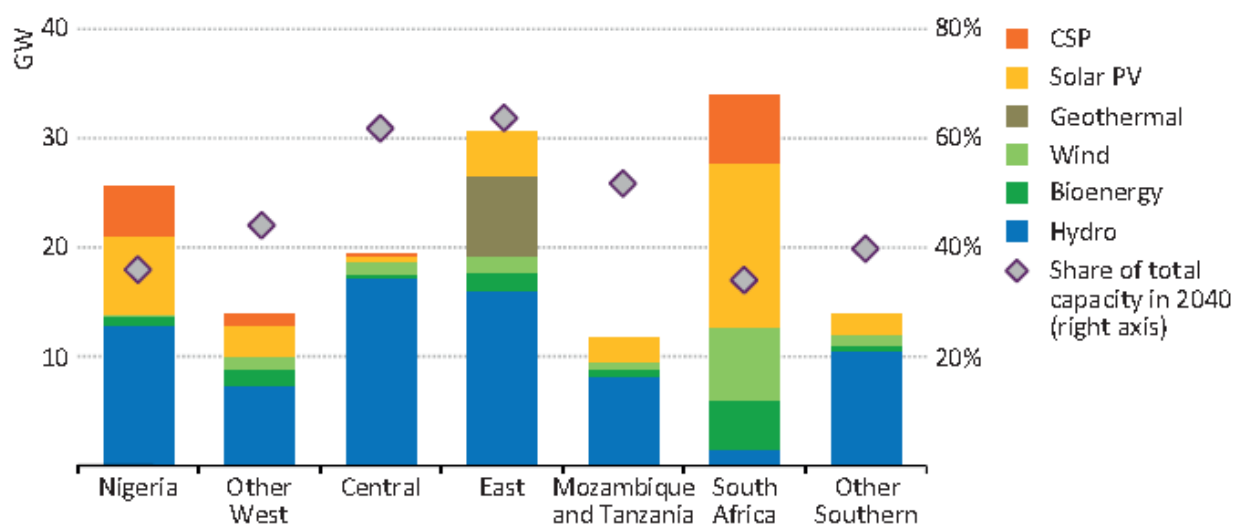
**Figure 8: Projected incremental coal-fired electricity generation in select regions through 2035 versus 2011 level, TWh**



Source: IEA, CTI/ETA analysis 2014

Finally, the fact that in the New Policies Scenario, coal-fired generation in India and Africa is not projected to increase more, speaks to the strong projected growth in other forms of electricity generation. The figure below, for example, shows the increase in renewables-based capacity by sub-region and type in sub-Saharan Africa in the most recent update to the New Policies Scenario through 2040.<sup>37</sup> Note that in every sub-region of sub-Saharan Africa nearly 40% or more of 2040 electrical capacity is related to renewables, with hydro and solar PV being particularly prevalent. This speaks to the significant opportunities that exist to meet growing energy demands from sources other than coal - a topic discussed in greater detail below.

**Figure 9: Increase in renewables-based capacity by sub-region and type in sub-Saharan Africa in the New Policies Scenario, 2012-2040**



Source: IEA

**Conclusion: The IEA NPS as a reference scenario involves a 23% increase in global coal consumption, however it does see coal losing market share to alternatives.**

<sup>37</sup> IEA, *Africa Energy Outlook*, Figure 2.19, 104.

***The IEA NPS does not deliver energy to the majority of those without access.***

While energy access is part of overall projections, trends in the New Policies Scenario do not directly illuminate the role of coal in providing universal electricity access, for the simple reason that in this scenario by 2030 there remain 969 million people without access to electricity (including 645 million in sub-Saharan Africa and 147 million in India). In the New Policies Scenario electricity deficits in sub-Saharan Africa are not addressed, with the number of people still lacking basic access to electricity in 2030 actually increasing to 645million.<sup>38</sup> India fares better with a reduction of around half to 147 million people.

**Table 2: Number of people without access to modern energy services by region in NPS, 2011 and 2030 (millions)**

	Without access to electricity		Without access to clean cooking facilities	
	2011	2030	2011	2030
<b>Developing countries</b>	<b>1 257</b>	<b>969</b>	<b>2 642</b>	<b>2 524</b>
Africa	600	645	696	881
Sub-Saharan Africa	599	645	695	879
Developing Asia	615	324	1 869	1 582
China	3	0	446	241
India	306	147	818	730
Latin America	24	0	68	53
Middle East	19	0	9	8
<b>World</b>	<b>1 258</b>	<b>969</b>	<b>2 642</b>	<b>2 524</b>

Source: IEA

**Conclusion: In the IEA New Policies Scenario, by 2030 three-quarters of the world's population lacking access to electricity remain without access to electricity.**

***Energy for All Case - achieving universal electricity access unlikely to significantly boost coal demand***

Given the coal industry's emphasis on achieving universal access to electricity, one might think that achieving this goal might augment future coal demand from Africa and India significantly above the level observed in the New Policies Scenario. It is possible to answer this question, however, by examining the IEA's "Energy for All Case"<sup>39</sup>, in which the world achieves universal access to electricity by 2030. Defining "access" to electricity as a consumption rate of 250-500 kWh per year (which, as discussed below, some analysts have critiqued as high<sup>40</sup>), the IEA estimate that achieving universal electricity access will increase global electricity demand in 2030 by roughly 1396 TWh above the level of 2030 demand in the New Policies Scenario. This amounts to an increase in 2030 electricity demand of only 4.1% relative to the New Policies Scenario.

<sup>38</sup> IEA, *WEO 2013*, 87-89.

<sup>39</sup> IEA, *WEO 2013*, 92-93.

<sup>40</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 4.

Moreover, of this additional 1396 TWh, the IEA projects that only 35% (i.e. 488 TWh) will come from fossil fuels, with the remainder coming from renewable generation sources such as hydro, wind, and solar. Even assuming that all of this amount came from coal, 488 TWh is equal to only 5.3% of global electricity generation from coal in 2011 (or 4.1% of projected global electricity generation from coal in 2030 under the New Policies Scenario). Applying the average proportion of fossil fuel-generated electricity projected in the New Policies Scenario to be supplied by coal to 2030, which is 44%, suggests that more accurately coal supply could be expected to grow by just 215 TWh over this period as a result of increased provision of energy access. This is equivalent to just 1.8% of projected electricity generation from coal globally by 2030 under the New Policies Scenario. As will be discussed in the next section this could easily be offset by extra gains in efficiency or reducing distribution losses.

Therefore, achieving the critical goal of universal electricity access by 2030 is likely to result in marginally higher future demand for coal than would prevail should nearly one billion people remain without access to electricity (as occurs in the New Policies Scenario), but any such increase could easily be mitigated by improvements in the electricity system.

**Conclusion: The IEA's "Energy for All Case" suggests that - due to both the small initial incremental electricity demand resulting from universal access, as well as competition from renewable generation sources - the boost to future coal demand is, through 2030 at least, likely to be minimal.**



## Rural populations set to grow in sub-Saharan Africa, logistics of grid extension challenging

Given the coal industry's focus on addressing energy poverty, the IEA's low estimated impact to fossil fuel demand from achieving universal electrification merits further analysis. Populations lacking access to electricity tend to be concentrated in rural areas. Currently, 84% of the global population without electricity live in rural areas.<sup>41</sup> Rural electricity deficits are particularly pronounced in sub-Saharan Africa, where the rural electrification rate is 18%, versus 55% in urban electrification rate). Within India the electrification rate is 94% in cities versus urban 67% in rural areas.

According to the UN, sub-Saharan Africa is forecasted to see an increase in the rural population due to the higher than average population growth predicted.<sup>42</sup> *The IEA projects that by 2040 90% of the sub-Saharan population without access to electricity will live in rural areas; moreover, this sub-Saharan rural population will comprise two-thirds of the global population without access to energy.*

### **Urbanization is not tantamount to energy access**

Although the problem of inadequate energy access will become an increasingly rural phenomenon (and, in particular, a sub-Saharan African rural phenomenon), the speed of urbanization in African and Indian cities has, in many cases, undermined the acquisition of improvements in basic living standards with it, including access to electricity. The World Bank state that 10% of the global urban population in developing countries lack access to electricity, equivalent to 226m people, while 56% do not have access in least developed countries, equivalent to 116m.<sup>43</sup> This population of over 300m typically reside in very poor quality slums.

For example, the city of Mumbai has over 6 million slum dwellers in a city of just under 12 million people in total. The large proportion of those living in slums do not have legal access to electricity, so illustrating that being an urban inhabitant in no way guarantees access to centralized coal-powered electricity. The urban resident population in Africa, which currently stands at 373 million, is expected to more than double by as early as 2030 according to the UN, making it the most rapidly urbanizing region on the planet.<sup>44</sup> Clearly therefore, without a lack of careful yet rapid planning, this already high population of slums dwellers without power could increase further.

### **Tackling distribution losses will help to offset projected demand increases**

Extending electricity to populations in rural areas will generally require a suite of solutions that is different from what is used to extend electricity access in urban areas. Specifically, the approach that has electrified cities throughout the world - which relies on delivering power from large, centralized generation - is often unfeasible due to lack of adequate transmission and distribution (T&D) infrastructure.

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<sup>41</sup> IEA, *World Energy Outlook 2011 Special Report - Energy for All*, Oct 2011, 3.

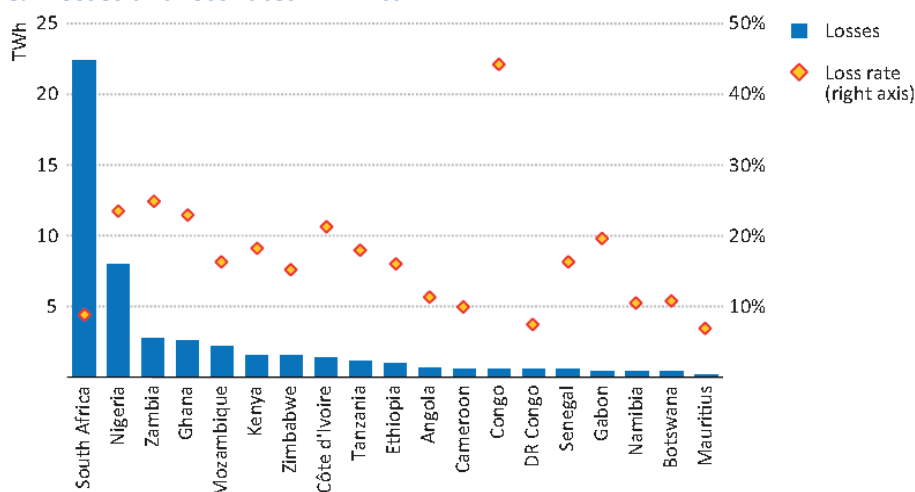
<sup>42</sup> UNDP, Demographic projections, the environment and food security in sub-Saharan Africa, <http://www.undp.org/content/dam/rba/docs/Working%20Papers/Demographic%20Projections,%20the%20Environment%20and%20Food%20Security%20in%20Sub-Saharan%20Africa.pdf>

<sup>43</sup> UN DESA, 'World Economic and Social Survey 2013', [http://www.un.org/en/development/desa/policy/wess/wess\\_current/wess2013/WESS2013.pdf](http://www.un.org/en/development/desa/policy/wess/wess_current/wess2013/WESS2013.pdf)

<sup>44</sup> Francis Owusu, 'Urban planning: The way forward for Africa's cities?' 14 September 2011, <http://thinkafricapress.com/population-matters/impact-demographic-change-resources-and-urban-planning-africa>

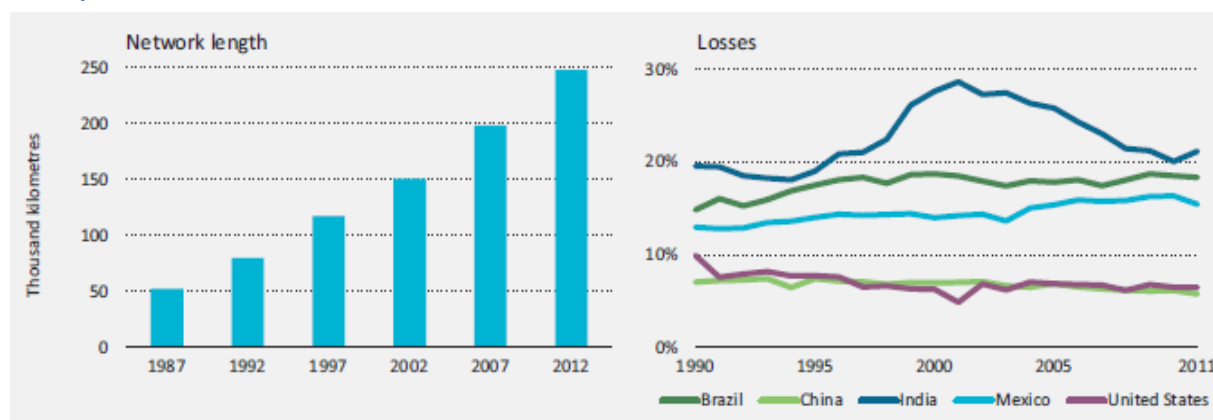
It is important to note that grid infrastructure throughout India and Africa is underdeveloped and displays high loss rates. Among other causes, losses result from a combination of poor system design, unreliable maintenance and operation, and illegal theft.<sup>45</sup> On average across sub-Saharan Africa, T&D losses reduce the supply ultimately available to end-use sectors by 18% (with losses in several countries exceeding 20%). Excluding South Africa, the loss rate in sub-Saharan Africa is more than double the world average and that of many developing countries in Asia. The same is true of India. In both India and sub-Saharan Africa, loss rates are three times the level in China and the US. Regrettably, for both technical and commercial reasons, reducing loss rates in these regions has proved challenging.

Figure 10: T&D losses and loss rates in Africa



Source: IEA

Figure 11: India's T&D network, physical expansion and electricity losses (3X US and Chinese levels)



Source: FICCI, 2013 (left); IEA data and analysis (right)

<sup>45</sup> In the context of India's power sector (though the comments apply as well to sub-Saharan Africa), the IEA notes that describes grid losses "are as "partly technical and partly commercial. Technical losses are primarily due to inadequate investment on maintenance and upgrading, which has resulted in ad hoc extensions of distribution lines, overloading of transformers and conductors, and lack of adequate reactive power support. Commercial losses largely result from theft; from defective meters, errors in meter reading and in estimating unmetered supply of energy; and from overconsumption by those receiving free or heavily subsidized electricity (e.g. agricultural sector)." IEA, *Energy Technology Perspectives 2014: Harnessing Electricity's Potential*, "Chapter 9: Power Generation in India," 2014, 313.

Such high loss rates reduce the reliability of the power supply, which is already insufficient to meet demand in most countries. In addition, high losses increase the cost of the power actually delivered. Across sub-Saharan Africa in 2012, the average cost of generating electricity was around \$115 per megawatt-hour (MWh). At an 18% loss rate, this translates (for generation costs alone) into around \$140 per MWh consumed, still without provision for the other substantial costs related to power supply. These additional costs, including the T&D infrastructure and retail costs, can add \$50-\$80 per MWh to the average cost to the consumer (as in China).<sup>46</sup>

Africa is forecasted to generate 1504TWh of power by 2030, while India is forecasted to supply 2725TWh over the same period. Both regions have above global average transmission and distribution losses. If the efficiency of these power grids was improved by a third, this would more than offset the extra 215TWh of coal generation that the IEA Energy4All scenario involves. Therefore, increasing grid efficiency in both Africa and India is an effective way to improve energy supply without increasing demand for coal.

**Conclusion: The majority of the energy access challenge relates to rural areas where there is limited infrastructure and major grid inefficiencies. Reducing distribution losses would be a significant contribution to improving electricity supply, which could more than offset any potential increase in coal use in urban areas under the Energy for All scenario.**

### ***Grid, mini-grid, and off-grid solutions***

Contrary to the coal industry's narrative of urbanization and centralized generation as the only path to energy access, the IEA "Energy for All Case" assumes three different types of solutions for energy access:

- grid extension
- mini-grid (small grid systems linking households and other consumers, but not connected to larger regional grids)
- isolated off-grid solutions (e.g. stand-alone systems for individual households or consumers).

The IEA notes that "a range of factors – including population density, tariffs for grid-based electricity, technology costs for mini-grid and off-grid systems and the final cost of diesel at the point of consumption – affect the optimal mix of grid-connected, mini-grid and off-grid generation options."<sup>47</sup> In the initial stages of energy access (e.g. for lighting, mobile phone charging, etc.), off-grid solutions are usually by far the most economical means of energy access.<sup>48</sup> As power requirements rise, however, delivering electricity through an established grid usually enables the lowest cost per MWh, and therefore been typically been the most cost-effective solution for urban areas or large rural settlements living within a limited distance from existing transmission and distribution lines.

<sup>46</sup> T&D infrastructure can be 30-35% of the cost of delivered energy, which is equal to \$50-80/MWh.

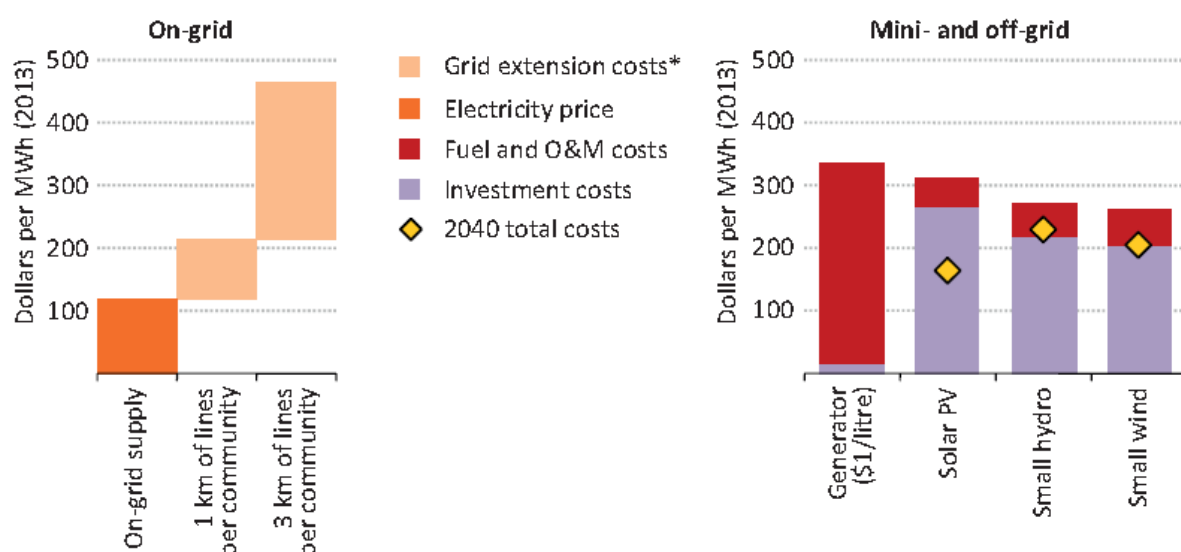
<sup>47</sup> IEA, WEO 2013, 92, note 23.

<sup>48</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," Table 3.

As discussed above, beyond a certain distance, however, the combination of increasing direct costs and high transmission losses make grid extension prohibitively expensive. In India, for example, every kilometer in distance between a household and the nearest substation adds \$0.02/kWh to the cost of delivered power; in Kenya, the cost of connecting a single family to the grid ranges from \$900-\$4000.<sup>49</sup> Given that poor households (once connected) generally consume relatively little electricity, access-related grid extension often offers a poor return on investment for electric utilities; hence utilities in weak financial condition to begin with (as is the case throughout India and sub-Saharan Africa<sup>50</sup>) are even less inclined to make such investments. And there is the reliability issues. This is all discussed in more detail in Section 2.

Given the potentially high costs of grid extension, mini-grids and off-grid solutions - including diesel generators (which are also not helpful environmentally – see below) and small-scale solar PV, wind, and hydropower systems - become more economical than grid extension as a means to provide electricity access (with the economics of off-grid relative to mini-grid solutions rising as population density falls). *Note that since 2012, installed prices for PV systems have continued to fall, reducing the cost of electricity from off-grid solar PV well below \$300/MWh.*

**Figure 12: Indicative levelized costs of electricity for on-grid, mini-grid and off-grid technologies in sub-Saharan Africa, 2012**



Source: IEA

\*Costs of grid extension are calculated as the average cost of extending the medium-voltage grid a certain distance (e.g. 1 km) to each community on a levelized cost basis.

Notes: Costs are indicative and could vary significantly depending on local conditions such as electricity tariffs, population density and the delivered cost of diesel. The quality of service for the different technologies also varies: additional investment in batteries or back-up power may be needed to compensate for the variability of renewables or intermittent grid supply. O&M = operation and maintenance.

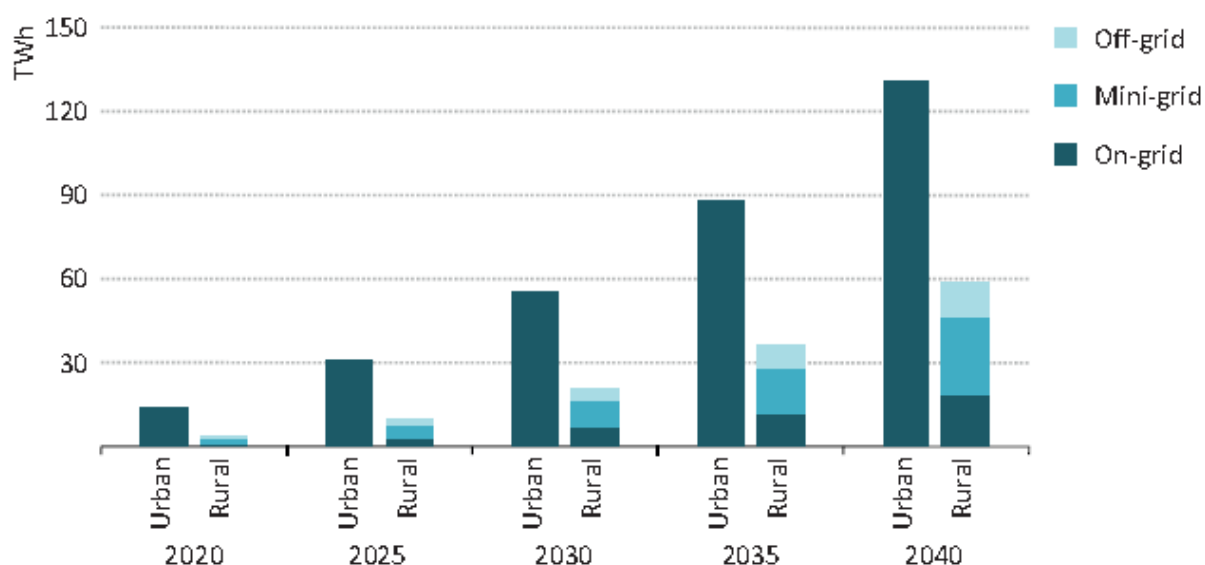
<sup>49</sup> Pope, "Powering the World's Poorest Economies: A Response to Bill Gates and Jigar Shah."

<sup>50</sup> As of 2010, the International Monetary Fund (IMF) reported operating deficits for sub-Saharan Africa's electric utilities equaled 1.4% of combined regional GDP (IMF, *Energy Subsidy Reform in Sub-Saharan Africa: Experiences and Lessons*, 2013, Washington, DC.) In 2011-2012 India's State Electricity Boards reported aggregate losses of Rs928bn (US\$15bn). Carbon Tracker Initiative (CTI) and Institute for Energy Economics and Financial Analysis (IEEFA), *Thermal coal demand: comparing projections and examining risks*, September 2014, <http://www.carbontracker.org>.

For all urban zones and roughly 30% of rural areas (not including any remote rural areas), the "Energy for All Case" in the 2013 WEO assumes grid extension to be the best option for providing electricity access. Of remaining rural areas, 65% are connected with mini-grids and 35% via stand-alone off-grid solutions (which have no T&D costs). This distribution of solutions underscores the constraints on use of centralized generation (including from coal) to provide energy access. *In the IEA's modeling of universal electrification by 2030, roughly 59% of those receiving access do so via mini-grid or off-grid solutions.*<sup>51</sup> Recognizing this explains why coal is an unlikely savior for much of the world's energy poor, who will require other solutions.

Within Africa specifically, the IEA's recent Africa Energy Outlook underscores the limited contribution of grid power to closing rural electricity deficits. In its 2014 New Policies Scenario - which, let it be clear, does *not* achieve universal electricity access - on-grid solutions play a very limited role in providing electricity access in rural areas (as the figure below illustrates).

**Figure 13: Electricity demand from the population gaining access to electricity in sub-Saharan Africa in the 2014 New Policies Scenario**



Source: IEA

**Conclusion: The most appropriate supply model for the majority (59%) of those currently without energy access is using mini-grids or off-grid, rather than large-scale centralized power generation. Mini grid and off-grid are cheaper options, especially in sub-Saharan Africa where there is very little existing grid infrastructure.**

<sup>51</sup> 70% of rural areas do not receive grid extension, and 84% of the global population without electricity live in rural areas. 70% \* 84% = 59%.

## Role of clean energy in meeting mini-grid and off-grid supply

In areas of India and Africa not connected to the electric power grid, the dominant technology for generating electricity is currently oil, in the form of diesel generators. Diesel generators, however, suffer from the problems of high (and volatile) operating costs, noise, and air pollution. Lighting technologies such as kerosene lamps have similar drawbacks. Fortunately, the declining costs of renewable energy technologies – in particular solar PV – are enabling cleaner options for off-grid electricity access. As hybrid systems are built, that will reduce the share of diesel in the overall mix.

### ***Energy Ladder - Early stages of energy access and growth of the off-grid market***

Note that for the poorest communities lacking access to the electricity grid, initial steps toward electrification are being provided by dedicated technologies such as solar lamps. The concept of the “energy ladder” refers to the critical initial interventions that enable communities to enjoy the benefits of electrification (e.g. lighting, mobile-phone charging, fans), but do not qualify as full electrification. Analysts from the Sierra Club, Lawrence Berkeley National Laboratory, and Village Infrastructure Angels note that “rather than waiting for all needs to be met at once (i.e. grid extension), off-grid interventions help get populations on the energy ladder on a time scale that accelerates impact: days and months, not the years and decades they often must wait for centralized power plants and grid extension. Lighting and mobile phone charging are the beginning, not the end of energy access.”<sup>52</sup> For the early stages of energy access (e.g. task lighting through to low power appliances), these analysts estimate that *off-grid solutions can provide energy access at only 4-20% of the cost of a grid connection.*

**Table 3: Definitions and costs of access to energy**

Access to Electricity Supply						
Attributes	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Service description	-	Task lighting and phone charging (OR radio)	General lighting AND television AND fan (if needed)	Tier 2 AND any low power appliances	Tier 3 AND any medium power appliances	Tier 3 AND any high power appliances
Peak available capacity (W)	-	> 1	> 50	>200	>2000	>2000
Duration (hours/day)	-	≥ 4	≥ 4	≥ 8	≥ 16	≥ 22
Evening supply (hours/day)	-	≥ 2	≥ 2	≥ 2	≥ 4	≥ 4
Average costs (US\$/household)						
Grid		2000	2250	2500	7500	8250
Minigrid		2500	2750	3200	8000	8800
Stand-alone		70	300	500	9500	10500
Minimum cost	0	70	300	500	7500	8250

Source: Sierra Club, LBNL, Village Infrastructure Angels Source

<sup>52</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 5.



The impact of clean energy technologies in expanding energy access is manifest in the rapid growth of solar-powered lighting technologies. The Lighting Africa program provides financing to aid deployment of solar-powered lights that can also charge mobile phones throughout sub-Saharan Africa. Since its inception in 2007, this program has grown at a 95% CAGR.<sup>53</sup> Sunny Money, a social enterprise of the UK-based charity Solar Aid, recently sold its one millionth solar light in sub-Saharan Africa. Focusing chiefly on Kenya and Tanzania, Sunny Money has sold over 614,000 solar lights in the past year alone. The group estimates that these lights are providing 3.9 million people with access to "clean, safe, bright light," resulting in 765 million extra study hours for children and \$126 million in savings for families (over the three-year lifetime of these solar lights).<sup>54</sup>

**Conclusion: Even in places that currently lack a centralized grid, low-cost off-grid interventions are enabling households with initial access to the "energy ladder" at a fraction of the cost of grid extension, providing immediate benefits.**

### ***Beyond solar lights - deployment of small-scale PV***

The role of solar-powered technologies in providing energy access is not limited to application-specific devices such as solar lights or phone chargers. The IEA observes that solar PV "can improve life considerably for those who earn USD 1 to USD 2 per day and spend as much as USD 0.4 per day on dry batteries, kerosene and other energy products."<sup>55</sup> Assuming a \$1 per liter (i.e. ~\$4/gallon) cost of diesel fuel (not unreasonable for remote areas with high transport costs), Figure 12 above indicates that the cost of electricity from small off-grid solar PV systems to be competitive with diesel generation (with savings on fuel costs compensating for the high capital costs of PV). The favorable economics of solar PV in off-grid markets are reflected in the dramatic growth in installations in energy-poor countries such as Bangladesh, where off-grid solar PV installations have grown at a 60% CAGR over the past decade, with 80,000 residential installations now being installed every month. Bangladesh's 3.3 million small-scale solar installations - which have supported growth of the seventh largest clean energy workforce in the world - underscore the benefits that solar PV is already bringing to rural communities throughout the developing world.<sup>56</sup>

Technological advances as well as increasing production economies of scale are expected to make solar PV increasingly competitive with diesel generation, as well as with other renewable technologies; this is particularly true for many parts of India and sub-Saharan Africa, where a strong solar resource supports reliable power production from PV panels throughout the day. The IEA projects that by 2040, "the delivered cost of diesel would have to be less than \$0.50 per liter (i.e. ~\$2/gallon) to be competitive with the anticipated cost of generation from solar PV."<sup>57</sup>

<sup>53</sup> Lighting Africa, *Lighting Africa Market Trends Report 2012: Overview of the off-grid lighting market in Africa*, June 2013, [http://www.dalberg.com/documents/Lighting\\_Africa\\_Market\\_Trends\\_Report\\_2012.pdf](http://www.dalberg.com/documents/Lighting_Africa_Market_Trends_Report_2012.pdf)

<sup>54</sup> Solar Aid, "Impact Report: Autumn 2014," October 2014, 4.

<sup>55</sup> IEA, *Technology Roadmap: Solar Photovoltaic Energy - 2014 Edition*, Sep 2014, Box 4, 25.

<sup>56</sup> Ben Willis, "Friday Focus: How Bangladesh became the world's largest off-grid solar user," *PVTech*, Jul 5 2013, [http://www.pv-](http://www.pv-tech.org/friday_focus/friday_focus_how_bangladesh_became_the_worlds_biggest_domestic_off_grid_pla)

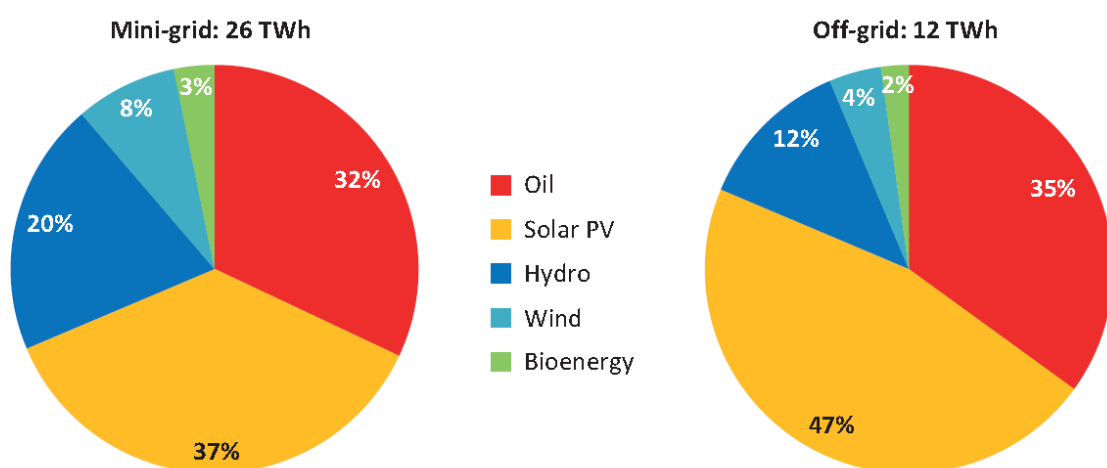
[tech.org/friday\\_focus/friday\\_focus\\_how\\_bangladesh\\_became\\_the\\_worlds\\_biggest\\_domestic\\_off\\_grid\\_pla](http://www.pv-tech.org/friday_focus/friday_focus_how_bangladesh_became_the_worlds_biggest_domestic_off_grid_pla)

<sup>57</sup> IEA, *Africa Energy Outlook*, 129.



Due to declining costs, the recent IEA solar PV roadmap assumes that by 2030 500 million people lacking other access to electricity will have a PV capacity of 200 W per person (i.e. enough to support general lighting, television, fans, and low-power appliances). This suggests a mini-grid and off-grid PV capacity of 100 GW, representing 5% of total installed PV capacity by 2030 (for reference in 2013 global installed PV capacity was 135 GW<sup>58</sup>). Moreover, although the absolute levels of generation are very low, in the IEA New Policies Scenario by 2040 solar PV supplies 40% of total generation in the combined mini-grid and off-grid market of sub-Saharan Africa. Note that inasmuch as declining battery enable greater use of solar output from PV/diesel/battery hybrid systems (as discussed below), this will increase generation from solar PV at the expense of diesel.

**Figure 14: Technology mix for mini-grid and off-grid power generation in sub-Saharan Africa in the New Policies Scenario, 2040**



Source: IEA

**Conclusion: Coal has little role to play in the mini-grid and off-grid solutions that are increasingly shifting to renewables as they are now becoming more cost-competitive.**

<sup>58</sup> IEA, *Technology Roadmap: Solar Photovoltaic Energy - 2014 Edition*, Table 3, 20.

## New technology, financing, and business models

Increasing deployment of solar PV and other technologies for renewable electricity generation are benefitting from a range of forces. These will be discussed in more detail again in section 2.

### **Hybrid PV-diesel systems - watch the batteries**

In discussing the role of solar PV in extending electricity access, the IEA observes that "an important consideration for off-grid or mini-grid systems is the ability to scale-up supply: options that provide electricity for lighting may not be sufficient to run a refrigerator, let alone to start a business." In addition to providing initial access, there is a role for solar PV to improve reliability and reduce electricity costs for areas that suffer from high-priced or unreliable electricity service.<sup>59</sup>

At present, solar PV is often best able to do so, however, if deployed as part of a "hybrid" system in combination with a diesel generator and, importantly as costs fall, a battery pack to store solar output. Hybridization with PV and a battery bank supply provides the opportunity to supply low load overnight using a battery system and the installed PV capacity level to cover partly or fully the morning and mid-day load – using the diesel generator to cover the evening peak and complete the battery charge if required. PV/diesel hybrid mini-grids can be a good fit good for rural electrification because they mitigate fuel price increases, deliver operating cost reductions and offer higher service quality than traditional single-source generation systems.

The IEA defines a hybrid generation system as:

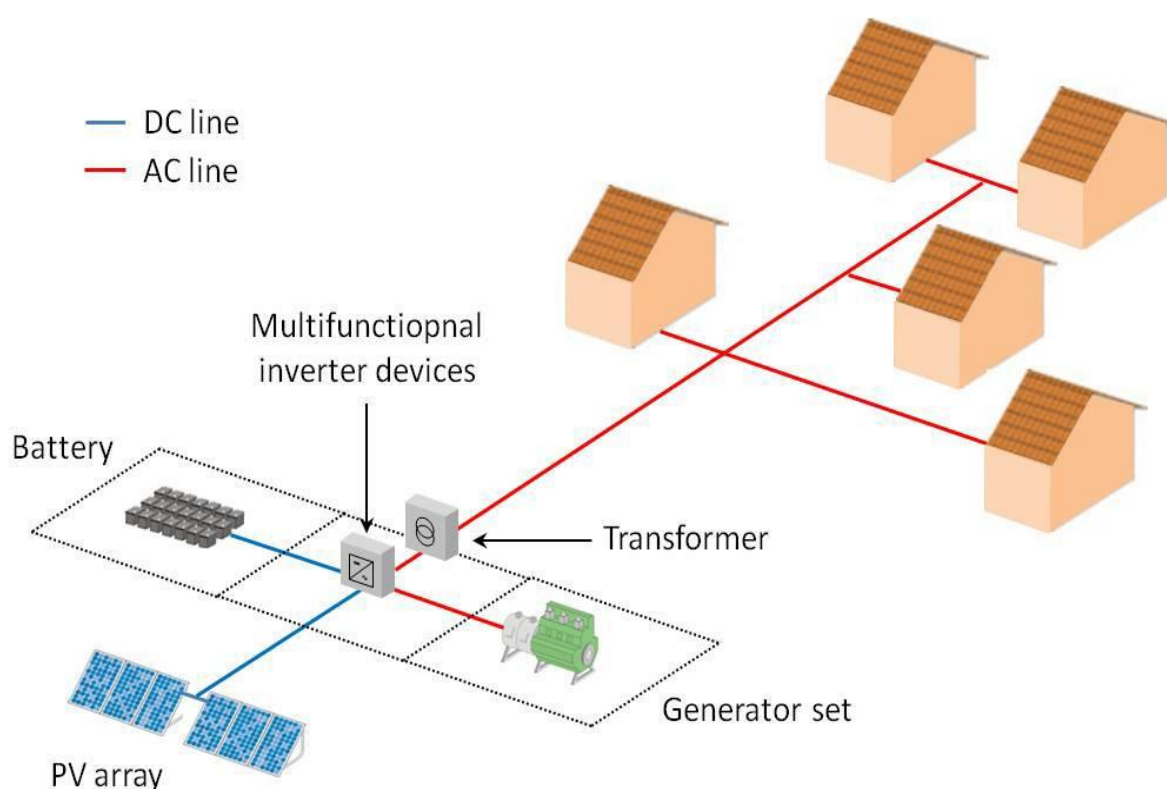
*"a system combining two (or more) energy sources, operated jointly, including (but not necessarily) a storage unit and connected to a local AC distribution network (minigrid). As PV power output is DC and minigrids operate in AC, at the heart of the hybrid system are the multifunctional inverter devices able to convert DC and AC currents, control the generation and storage systems and set up the voltage and frequency of the minigrid."*<sup>60</sup>

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<sup>59</sup> The discussion above, for example, noted that grid losses in India and sub-Saharan Africa are three times the level in the US and China.

<sup>60</sup> IEA, "Rural Electrification with PV Hybrid Systems: Overview and Recommendations for Further Deployment," Photovoltaic Power Systems Program, Report IEA-PVPS T9-13:2013, 7

Figure 15: Schematic view of a PV / diesel hybrid system



Source: IEA

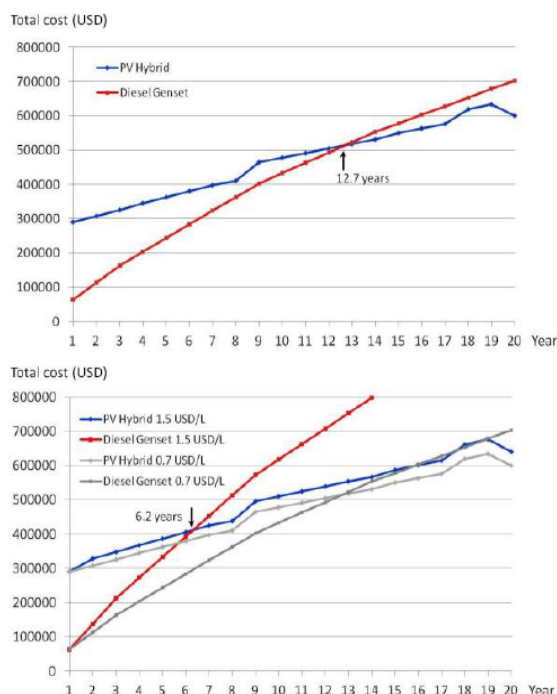
For recently installed PV/diesel hybrid systems in Africa and Asia as of July 2013, the IEA report real installed costs in a range of \$7000-\$11400/kWp. The chart below indicates the portion of system costs attributable to each component (which varies by system size and geography). The combination of PV panels and support, inverters, and battery bank account for ~70% of the installed cost of a diesel hybrid system. The return on investment for this additional capital costs depends on the ability of a hybrid system to lower fuel costs by reducing diesel consumption.<sup>61</sup> Potential fuel savings will depend, among other things, on the shape of the site's "load profile" (i.e. demand for electricity), the local cost of diesel, and battery storage capacity.

The dramatic decline in prices of PV modules over the past decade has improved the economics of hybrid PV/diesel systems considerably. Even amid this decline, however, attractive economics for hybrid systems have often depended on a high price for diesel. For example, using 2011 data, the figure below illustrates the 20-year economic profile for a 60 kWp PV/diesel hybrid system.<sup>62</sup> Assuming a constant fuel cost of \$0.70/liter, moving from a diesel to a hybrid system reduces LCOE by 15%. The simple payback period for investment in such a system, however, is 12.7 years; only assuming a higher fuel cost of \$1.5/L does the simple payback period fall to a more attractive 6.2 years. *As discussed in greater detail during the section on hybrid systems for commercial enterprises, declining costs for battery storage are serving to improve the economics of hybrid systems.*

<sup>61</sup> There may be potential additional benefits by minimizing exposure to fuel price spikes or fuel shortages

<sup>62</sup> IEA, "Rural Electrification with PV Hybrid Systems: Overview and Recommendations for Further Deployment," 15. This data is for a rural system in Ecuador. As the key inputs to such a system (PV panels, diesel generation equipment, and batteries) are commodity products, however, costs for an urban system ought to be similar.

Figure 16: Example of 60 kWp PV / diesel hybrid system: simulation of total accumulated costs over 20 years (2011 data)



Energy data	
Solar resource	6 kWh / m <sup>2</sup> / day
Energy demand	266 kWh / day
Peak load	26 kW
Fuel cost (constant)	0.7 USD / L
Cost of components	
Genset 30 kVA	400 USD / kW
PV 60 kWp	2 822 USD / kWp
Battery	225 USD / kWh
Converter	1 445 USD / kW
Lifespan of components	
Genset	25 000 hours
Battery	8 years
<b>Break-even point</b>	<b>12.7 years</b>

Source: [2]

Impact of higher fuel cost	
Fuel cost (constant)	1.5 USD / L
<b>Break-even point</b>	<b>6.2 years</b>

Adapted from [2]

Source: IEA

Governments of several African countries have taken activities to promote adoption of hybrid systems. For example, the Government of Mali is adding PV capacity to its diesel power plants in order to create hybrid PV-diesel min-grid systems. Tanzania's Rural Electrification Agency is pursuing a similar strategy, focusing on adding hybrid diesel-PV systems to remote areas that are expected to remain isolated from the country's main grid through 2020. Activity on hybrid PV/diesels systems is also underway in Senegal, Tanzania, Rwanda, Mauritania, Uganda, Kenya, Burkina Faso and Madagascar.<sup>63</sup>

**Conclusion: Hybrid systems offer the flexibility to increase use of PV over time, as costs fall and storage technology advances, rather than locking economies into coal infrastructure.**

### Tower Power

One particularly promising application of hybrid PV systems is to provide so-called "tower power." Over the past 15 years, the spectacular growth in mobile phone penetration in developing countries has created a distributed infrastructure of over 600,000 off-grid cell phone towers.<sup>64</sup> To reduce reliance on costly and polluting diesel generators, mobile operators are among the most active adopters of clean energy technologies such as solar PV, often in the form of hybrid diesel-battery-PV systems.

<sup>63</sup> Bernard Tenenbaum, Chris Greacen, Tilak Siyambalapitiya, and James Knuckles, *From the Bottom Up: How Small Power Producers and Mini-Grids Can Deliver Electrification and Renewable Energy in Africa*, The World Bank, 2014,

<https://openknowledge.worldbank.org/bitstream/handle/10986/16571/9781464800931.pdf?sequence=1>

<sup>64</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 7-8.

Analysts from the Sierra Club, LBNL, and Village Infrastructure Angels note that *“telecom towers are often grossly under loaded compared to the power supplied to the tower (e.g. a 3kW load compared to a 15kW installed capacity), and re-lamping households connected to the grid can free up power cheaply and more quickly than building new power generation.”*<sup>65</sup>

Rather than using this energy just to power the cell tower, however, an emerging "tower power" model uses demand from the cell tower as a base from which to then distribute power to adjacent communities. Over-sizing the energy capacity of the cell tower creates surplus energy that entrepreneurs can then sell to surrounding communities via batteries, mini-grids, or direct on-site charging. The innovation in this model is to leverage the predictable revenue stream afforded by the cell tower, which reduces risk for entrepreneurs who are investing in the clean energy capacity. These analysts conclude that the tower power model *"surpasses the need for centralized grid infrastructure by piggybacking on the most successful leapfrog technology to date: mobile phones."*<sup>66</sup> With the Groupe Speciale Mobile Association projecting the potential for 200,000 "tower power" projects worldwide, this model appears capable of delivering electricity to 120 million people.<sup>67</sup>

### ***Pay-as-you-go-financing***

A second key area of innovation supporting growth of distributed solar is the adoption of pay-as-you-go (or "solar as a service") financing models. Even when solar systems offer an attractive return on investment, deployment is often stymied due to high upfront costs. In the US and other developed markets, this problem is being overcome due to the "solar lease", under which a customer pays no upfront cost and instead enters into a long-term contract to purchase the energy generated by the solar system at some agreed-upon rate. Solar leasing has contributed to the dramatic growth of residential solar PV installations in the US. Pay-as-you go solar financing is now being brought to the developing world by firms such as Off Grid Electric, M-Kopa, Simpa, and Angaza.

In the developing world, pay-as-you-go solar financing schemes are making extensive use of mobile money platforms and Machine to Machine (M2M) technology, which enables customers to purchase energy in small quantities as they consume it.<sup>68</sup> With mobile phone penetration in developing countries now approaching 75 percent (versus one percent in 1998), this creates a distributed infrastructure for provision of energy services in developing countries. Though pay-as-you-go solar via mobile money platforms is still in its infancy, in just 2013 sub-Saharan Africa saw sales of 60,000 pay-as-you-go solar services.<sup>69</sup> In Kenya alone, M-pesa has "enabled over 15 million people to access the financial system and accounts for \$12.3 billion in transactions."<sup>70</sup>

**Conclusion: The firms mentioned above focus on the off-grid market, but pay-as-you-go solar financing also has the potential to promote deployment within grid-connected market segments (discussed below)**

<sup>65</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 7.

<sup>66</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 7-8.

<sup>67</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 7-8.

<sup>68</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 7.

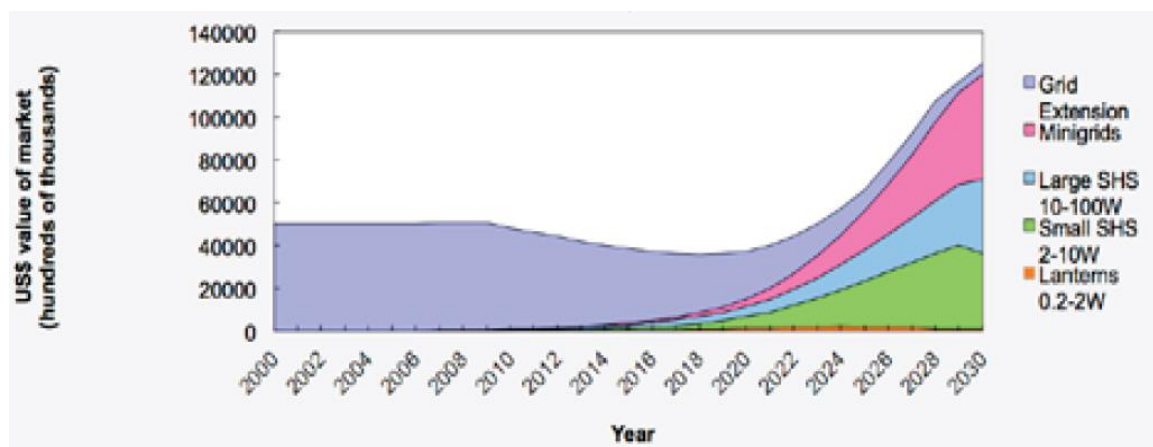
<sup>69</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 7-8.

<sup>70</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 7-8.

### ***Economic opportunities in off-grid: toward a \$12 billion annual market***

Today, excluding grid extension, the "energy access" industry is estimated to be a \$200-250 million industry annually. Analysts from the Sierra Club, LBNL, and Village Infrastructure Angels, however, project that annual investment of \$170 million will support a 26 percent compound annual growth rate that will enable exponential growth that reaches a \$12 billion annual market by 2030. In these projections, by 2030 the solar lantern market will reach \$125 million per year in investment opportunities while the mini-grid and solar home system segments will each reach \$5-\$7 billion. By way of comparison, in 2013 the U.S. residential market for solar was "only" \$3.76 billion."<sup>71</sup>

**Figure 17: Projected retail value of installed off-grid retail systems through 2030 (hundred-thousand USD)**



Source: Sierra Club, LBNL, Village Infrastructure Angels

### ***Result of innovation is reduced cost of off-grid electrification***

Analysts from the Sierra Club, LBNL, and Village Infrastructure Angels note how innovations – from LEDs to “tower power” – are enabling energy needs to be met with a fraction of the cost that had previously been required. Whereas the IEA projects that achieving its “Energy for All” case will require \$48 billion per year, these analysts estimate that the same level of energy access is possible for \$14 billion per year – which is a 71% reduction from IEA estimates.<sup>72</sup> *This potential for dramatic reduction in the cost of new energy alternatives is critical to bear in mind in the following sections, when we analyze alternatives to coal within the grid-connected market.*

**Conclusion: Off-grid solar is combining with other technologies and alternative financing models to accelerate roll-out and reduce cost of delivery.**

<sup>71</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 2.

<sup>72</sup> Craine, Mills, and Guay, "Clean Energy Services for All: Financing Universal Electrification," 6.



## Section Two: achieving high-renewable solutions to energy poverty

### Economic, environmental, and financial barriers to deployment of coal-fired generation

As opposed to providing initial access to energy, a more realistic source of growth in future coal demand results from the economic imperative for countries in Asia and sub-Saharan Africa to provide cities and businesses with reliable and affordable power. Even within this grid-connected market, however, there are barriers to coal serving as the "base fuel for power and steel to urbanize a world of over 9 billion people by 2050."<sup>73</sup> These barriers involve a combination of economic, environmental, and financial issues that we survey briefly below. The impact of these barriers informs our view that, for example, coal-fired electricity generation in India will likely grow much more slowly than in the IEA New Policies Scenario projections (even without implementation of robust global climate policies).

#### ***Cost of coal-fired electricity in India and sub-Saharan Africa: recent examples of \$90/MWh***

The bull case for coal-fired generation in emerging markets rests on the premise that coal is abundant and affordable. In explaining the decision to add nearly 10 GW of supercritical coal-fired generation by building the Medupi and Kusile power stations, South Africa's Finance Minister of the Pravin Gordhan argued that "we have no choice but to build new generating capacity -- relying on what, for now, remains our most abundant and affordable energy source: coal."<sup>74</sup> In South Africa and elsewhere, the cost of coal-fired electricity (excluding health and environmental impacts) is often lower than the cost of electricity from other sources. For example, for both supercritical<sup>75</sup> coal plants in South Africa and subcritical coal plants throughout sub-Saharan Africa, the IEA estimates a levelized cost of electricity (LCOE)<sup>76</sup> of roughly \$40/MWh<sup>77</sup>, which makes coal the lowest-cost generation option.

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<sup>73</sup> Peabody Energy, 19.

<sup>74</sup> Lisa Friedman, "New South African Coal Plant Seeks Emissions Credits for 'Cleaner' Coal," *New York Times*, June 2 2010, <http://www.nytimes.com/cwire/2010/06/02/02climatewire-new-south-african-coal-plant-seeks-emission-44705.html?pagewanted=all>

<sup>75</sup> Subcritical steam coal plants in Africa and India achieve gross lower-heating value combustion efficiencies of 34-35%; by raising the temperature and pressure under which combustion occurs, more advanced coal technologies can increase these efficiencies, for example to 38-39% for supercritical plants, and 41-42% for ultra-supercritical and integrated gasification combined cycle (IGCC) plants. Higher combustion efficiencies reduce the amount of pollution per unit of electricity generated. IEA, "Power Generation in the New Policies and 450 Scenarios - Assumed investment costs, operation and maintenance costs and efficiencies in the IEA World Energy Investment Outlook 2014," 2014.

<sup>76</sup> The US Energy Information Administration (EIA) notes that "Levelized cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competitiveness of different generating technologies. It represents the per-kilowatthour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type." EIA, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014," Apr 17 2014, [http://www.eia.gov/forecasts/aeo/electricity\\_generation.cfm#3](http://www.eia.gov/forecasts/aeo/electricity_generation.cfm#3).

<sup>77</sup> IEA, *Africa Energy Outlook*, Figure 1.25, 58, and Figure 3.16, 153.



The cost of electricity from Africa's largest new coal-fired projects, however, is likely to come in substantially above this \$40/MWh level. In the case of the 4.8 GW Medupi power station (scheduled to begin generating electricity at the end of 2014), South Africa's electricity regulator has estimated that the plant's LCOE will be the equivalent of \$90/MWh.<sup>78</sup> Given that capital costs per GW (including financing charges) for the Kusile plant (scheduled to come online in 2018) are estimated to be 36% higher than for Medupi, it seems possible that Kusile's LCOE could exceed \$100/MWh. Costs for these two projects (which, once completed, are set to be the third and fourth-largest coal plants in the world) have ballooned owing to (1) construction delays and consequent racking up of \$2.3-\$3.7 billion of interest charges; and (2) in the case of Kusile, "overnight costs" (i.e. for the cost of construction excluding financing) that - at \$2300/kW - are 42% higher than the IEA's estimated level for supercritical coal plants in Africa.<sup>79</sup> Cost overruns at the Medupi and Kusile plants are one reason why electricity tariffs in South Africa are set to increase by 12.69% in 2015 (i.e. by twice the rate of inflation), which will do little to enhance the country's economic competitiveness.<sup>80</sup>

The cost pressures on coal suggested by the Medupi and Kusile plants are also evident in India. For example, the estimated LCOE from India's recently built coal-fired generators (most of which use subcritical technology) also equates to about \$90/MWh.<sup>81</sup> In the case of India, the chief cost driver has not been construction delays and capital costs but rather the cost of imported coal (which is twice what India pays for domestic coal). The net result, however - of coal-fired electricity costing (or projected to cost) roughly \$90/MWh - is a critical data point in evaluating coal's role in powering economic growth throughout India and sub-Saharan Africa.

**Conclusion: \$90/MWh is the revised LCOE cost of the most recent example of the new Medupi coal plant in South Africa, indicating that new coal-fired generation may be above expectations.**

<sup>78</sup> Lynley Donnelly, "Eskom grilled on power price," 24 Aug 2012, *Mail & Guardian*,

<http://mg.co.za/article/2012-08-24-00-eskom-grilled-on-power-price%204.8%20GW%20Medupi%20Power%20Station>;

Linda Ensor, "Medupi likely to cost R35bn more than first estimated," *Business Day Live*, 26 Sep 2014,

<http://www.bdlive.co.za/business/energy/2014/09/26/medupi-likely-to-cost-r35bn-more-than-first-estimated>

<sup>79</sup> IEA, "Power Generation in the New Policies and 450 Scenarios." As Medupi and Kusile are South Africa's first supercritical coal plants, some might dismiss a portion of cost-overruns as aberrant "first-of-a-kind" costs that will decline for future projects. The tendency to favor large, centralized generation, however, limits opportunities to reduce costs through learning-by-doing (e.g. Medupi was South Africa's first coal plant in 15 years).

<sup>80</sup> Tamar Kahn and Paul Vecchiatt, "Tariff hike for Eskom 'will just be start,'" *Business Day Live*, Oct 6 2014, <http://www.bdlive.co.za/business/energy/2014/10/06/tariff-hike-for-eskom-will-be-just-the-start>

<sup>81</sup> Tim Buckley, "Briefing Note: Indian Power Prices," IEEFA, May 6 2014, Figure 5, 7,

<http://www.ieefa.org/press-release-the-beginning-of-the-end-of-imported-coal-in-india-report-exposes-economic-flaws/>. Natalie Obiko Pearson, "India Faces Mounting Calls to Move to Fixed Solar Tariffs," *Bloomberg*, Oct 13 2014,

<http://www.bloomberg.com/news/2014-10-13/india-faces-mounting-calls-to-move-solar-to-fixed-tariffs.html>

## ***Comparing the cost of coal-fired electricity against the cost of electricity from low-carbon renewables***

There is no denying that energy demand is likely to increase in countries with limited access at present. We find, however, that the potential for renewable electricity sources to penetrate the Indian and African markets at scale and at a competitive price to have been repeatedly underestimated. For example, in April 2014 the Indian Planning Commission published a report forecasting a tripling of wind, solar and biomass share of electricity generation to 18% by 2030, taking wind capacity to 120GW and solar to 100GW.<sup>82</sup>

Comparing the costs of different electricity sources is a difficult task. A measure such as LCOE, for examples, fails to differentiate between generation that can and cannot produce power on demand; from an electricity system perspective, however, there is significant value to generation that is "dispatchable" (and, conversely, there is cost associated with generation that is variable).<sup>83</sup> That said, comparing LCOE levels gives at least a rough indication of the economic competitiveness of different generation options.

In the context of India and sub-Saharan Africa, it is well known that large hydropower, geothermal, and biomass projects can generate electricity for below \$90/MWh (and, in the case of hydropower, often below \$50/MWh). More recently, however, continued declines in technology costs have enabled onshore wind and solar PV projects to come online with costs near or below \$90/MWh. In the case of onshore wind in India, Bloomberg New Energy Finance (BNEF) and the World Energy Council estimate an LCOE range of \$47-\$113/MWh;<sup>84</sup> combined with wind capital costs that are the lowest in the world, the terrific wind resource in states such as Karnataka (in southwest India) is what enables select Indian wind projects to generate electricity for less than \$50/MWh. Across India, the average wholesale cost of wind-powered electricity is roughly \$65/MWh.<sup>85</sup> Similarly, in Round 3 (May 2013) of South Africa's Renewable Energy Independent Power Producer Procurement Program (REIPPPP), electric utility Eskom sanctioned 787 MW of wind power projects at an average tariff of \$75/MWh.<sup>86</sup>

<sup>82</sup> Jairam Ramesh, "Germany's great green gamble," *The Hindu*, Sep 8 2014, <http://www.thehindu.com/opinion/op-ed/germanys-great-green-gamble/article6388737.ece?homepage=true>

<sup>83</sup> In a 2013 report on the cost of energy technologies, the World Energy Council and Bloomberg New Energy Finance note that their LCOE estimates "demonstrate electricity generation costs only, and thus do not represent the total cost of electricity supply such as grid connection or balancing costs for integration of volatile and intermittent renewable energy sources." *World Energy Perspective: Cost of Energy Technologies*, 2013, [http://www.worldenergy.org/wp-content/uploads/2013/09/WEC\\_J1143\\_CostofTECHNOLOGIES\\_021013\\_WEB\\_Final.pdf](http://www.worldenergy.org/wp-content/uploads/2013/09/WEC_J1143_CostofTECHNOLOGIES_021013_WEB_Final.pdf). Similarly, the EIA observes that "while LCOE is a convenient summary measure of the overall competitiveness of different generating technologies, actual plant investment decisions are affected by the specific technological and regional characteristics of a project, which involve numerous other factors" such as projected utilization rate, existing resource mix, and capacity value. EIA, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014."

<sup>84</sup> World Energy Council and BNEF, *World Energy Perspective: Cost of Energy Technologies*.

<sup>85</sup> Buckley, "Briefing Note: Indian Power Prices," Figure 5.

<sup>86</sup> Anton Eberhard, Joel Kolker, and James Leigland, "South Africa's Renewable Energy IPP Procurement Program:

Success Factors and Lessons," May 2014, <http://www.gsb.uct.ac.za/files/PPIAFReport.pdf>.

With respect to solar PV, South Africa's most recent REIPPPP auction contracts awarded for 435 MW of capacity at an average tariff of \$100/MWh, (10USc/kWh).<sup>87</sup> \$100/MWh was also the average tariff for solar PV projects in India's most recent national solar auction.<sup>88</sup> Note that in the case of India, however, this price included a government subsidy for 30% of the upfront investment cost. Across India, BNEF estimate a current LCOE range for Indian solar PV projects of \$87-\$137/MWh.<sup>89</sup>

**Table 4: Indicate levelized cost of electricity (LCOE) for grid-connected generation in sub-Saharan Africa (USD/MWh)**

	IEA	SA Electricity Regulator	Results of SA REIPPPP* Round 3	CTI analysis
Coal subcritical	40			
Coal supercritical**		90		
Large hydro	55			
Biomass			95-142	
Onshore wind	95		75	
Solar PV (large)	175		100	120-150***
CSP			166	
Average wholesale generation costs	55-140			

*Note: IEA estimates, most recent available, are for 2012; continued decline in solar PV system costs from 2012-2014 explains difference between IEA and CTI estimates. Average wholesale generation costs reflect regional averages, which range from \$55/MWh in southern Africa to \$140/MWh in west Africa.*

*\*South Africa Renewable Energy Independent Power Producer Procurement Program. Round 3 occurred in May 2013.*

*\*\*Reflects estimate of cost of electricity from South Africa's 4.8 GW Medupi plant, which is scheduled to begin operation at the end of this year. Converted to USD at a rate of 1 USD = 11 ZAR.*

*\*\*\* Reflects latest cost data for Kenya and assumes 9% discount rate; at a 5% discount rate the LCOE range would be reduced to \$90-120/MWh.*

*Sources: IEA, National Electricity Regulator of South Africa, Eberhard/Kolker/Leigland, CTI analysis 2014*

**Table 5: Indicate levelized cost of electricity (LCOE) for grid-connected generation in India (USD/MWh)**

	IEEFA*	BNEF/WEC**	IEA
Coal (domestic)	40-60		
Coal (imported)	87-92		
Biomass		65-86	
Onshore wind	74	47-113	
Solar PV		87-137	
CSP (no storage)		123-248	
CSP (with storage)			146-213***

*\*Reflects estimates for 2018 commissioning. Converted to USD at a rate of 1 USD = 61.3 INR. With assumed tariff inflation of 4% per year for imported coal, IEEFA projects India's cost to generate electricity from imported coal to rise to \$90-100/MWh by 2020, \$100-110/MWh by 2025, and \$120-130/MWh by 2030.*

*\*\* The given range is an average scenario range and does not reflect actual maximum and minimum values*

*\*\*\* Global range for 2015 new-built CSP plants in the IEA 2DS hi-Ren Scenario (assumes 8% discount rate).*

*Sources: IEEFA, BNEF/WEC, European Commission, IEA*

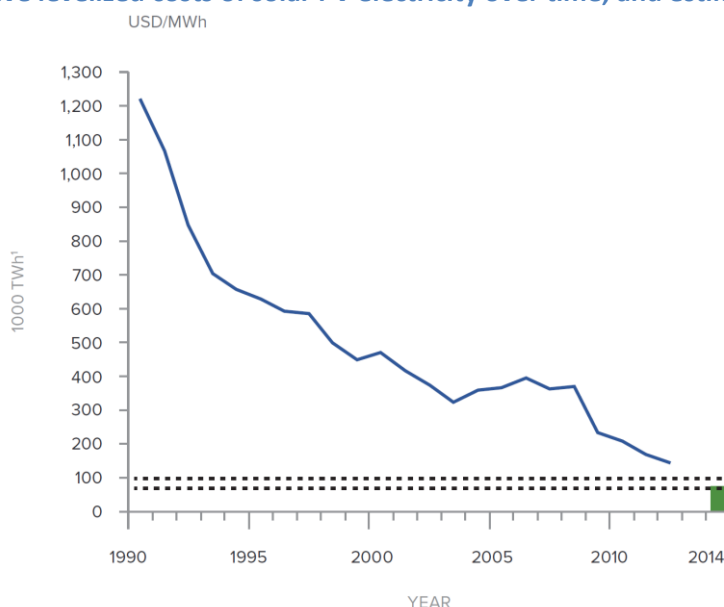
<sup>87</sup> As discussed below, for other markets in Africa where the cost of capital is somewhat higher than in South Africa, we estimate a current LCOE from utility-scale lower projects as low as \$120/MWh.

<sup>88</sup> Natalie Obiko Pearson, "India Faces Mounting Calls to Move to Fixed Solar Tariffs."

<sup>89</sup> World Energy Council and BNEF, *World Energy Perspective: Cost of Energy Technologies*.

Note that the costs cited above for solar PV reflect the dramatic reduction in the cost of grid-connected solar power over the past several decades. For example, the chart below reflects that low-cost utility-scale systems are now being installed for a \$/MWh cost that is 8% below what it was in 1990. This speaks to the tremendous potential for technological innovation that is being harnessed to reduce the cost of capital-intensive renewable generation technologies.

**Figure 18: Indicative leveled costs of solar PV electricity over time, and estimated lowest utility-scale**

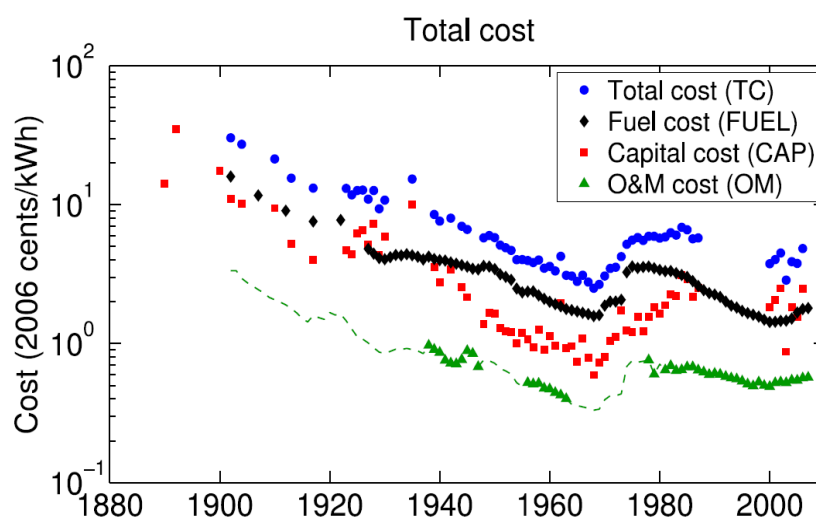


*Note: Solar PV costs can vary by ~50% or more up or down depending on solar resource and local non-technology costs, and even more with variations in capital and financing costs. Assuming 9.25% WACC, 17% capacity factor for solar PV, US\$70/t coal price and US\$10/MMBtu natural gas price. The estimated lowest 2014 utility-scale cost is based on a recent power purchasing agreement by Austin Energy, Texas (adjusted for subsidies).*

*Sources: Global Commission on the Economy and Climate, based on historical solar PV costs: Channell et al., 2012, and Nemet, 2006; illustrative fossil fuel range based on US LCOE for conventional coal from US EIA, 2014 (upper range) and capital cost assumptions from IEA, 2014 (lower range).*

Conversely, note that the cost of coal-fired power has over the past several decades has in most regions shown no comparable decline. Largely this is because much of the cost of coal-fired electricity reflects the cost of fuel (i.e. coal itself). As a commodity, coal prices tend to fluctuate over time but – even in an environment of structurally declining demand (as might occur in a carbon-constrained world) – don’t display the sharp reduction in cost that has been observed in, for example, solar modules over the past few decades. As evidence of this, consider the figure below, which shows the price of coal-fired power in the US (from 1882-2006) fluctuating over time (particularly over the last few decades) with no discernible trend.

Figure 19: The total cost of coal-fired electricity in the US, 1882-2006 (cents/kWh)



Sources: McNerney, Farmer, and Trancik<sup>90</sup>

### Cost reductions making solar power increasingly competitive

In India, the lowest-cost projects (in high-sun regions such as Rajasthan and Gujarat ) are already generating power for less than the ~\$90/MWh cost that Indian coal plants currently pay to generate electricity from imported coal. Assuming the rate of cost-reduction projected in the IEA's 2DS hi-Ren scenario (discussed below), by 2020 this would also be true of India's mid-range PV projects (which would have an LCOE of roughly \$87/MWh). *The increasing competitiveness of solar PV in the Indian market is one reason why Coal India (one of the world's largest coal mining companies) is evaluating the possibility to invest \$1.2 billion in the development of 1000 MW of solar power plants.*<sup>91</sup>

In Africa, utility-scale PV systems already appear competitive with the \$140/MWh average cost of generation in West Africa and nearly competitive with the \$90-\$110/MWh average cost of generation in East and Central Africa. Assuming projected cost reductions in the IEA's hi-Ren scenario (and no increase in the average cost of competing generation), *utility-scale PV will be soundly competitive against average wholesale generation costs in East Africa by 2020 and in Central Africa by 2020-2025.* With respect to Southern Africa, the IEA's projected cost-reduction pathway suggests that per-MWh costs for utility-scale PV can by 2020 be lower than the \$90/MWh cost of South Africa's new supercritical coal plants and by 2025 be lower than the \$70/MWh that Eskom (the national utility) is currently paying independent power producers to fill the country's electricity gap.<sup>92</sup>

Though costs for CSP are on a slower decline trajectory, projected steady improvement in this technology is significant. This is because CSP projects can use various thermal storage media (e.g. molten salts) to make their output "dispatchable," hence enhancing their value to grid operators. This storage ability makes CSP a useful complement to solar PV; whereas PV output peaks in the

<sup>90</sup>James McNerney, J. Doyne Farmer, and Jessika E Trancik, "Historical Costs of Coal-Fired Electricity and Implications for the Future," 2012, <http://arxiv.org/pdf/1001.0605.pdf>

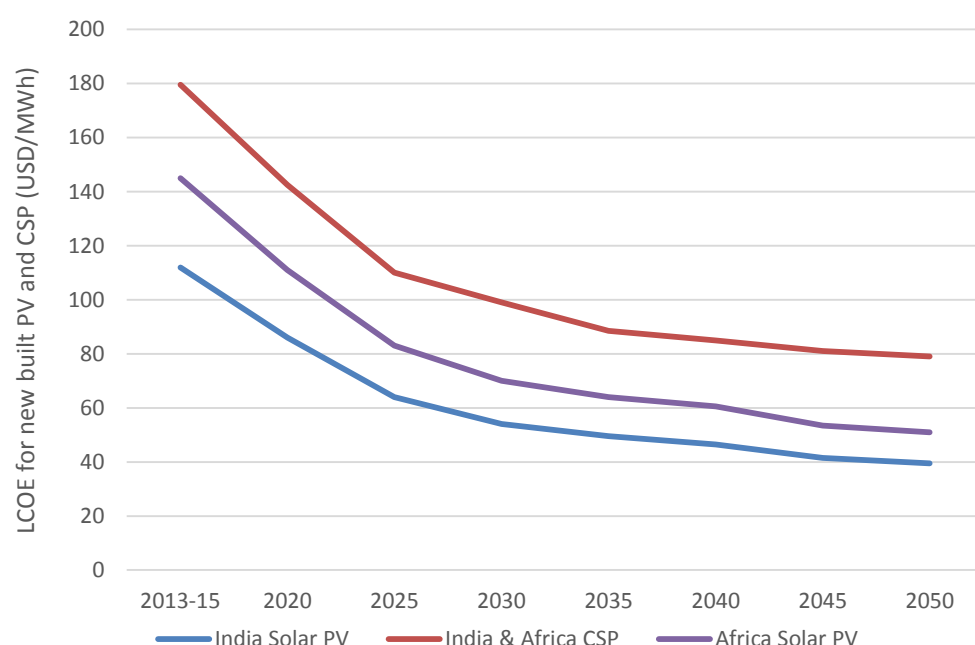
<sup>91</sup>Mridul Chadha, "World's Largest Coal Miner to Invest \$1.2 billion in Solar," *CleanTechnica*, Sep 24 2014, <http://cleantechnica.com/2014/09/24/worlds-largest-coal-miner-invest-1-2-billion-solar-power/>

<sup>92</sup>Lynley Donnelly, "Eskom grilled on power price," 24 Aug 2012, *Mail & Guardian*, <http://mg.co.za/article/2012-08-24-eskom-grilled-on-power-price%204.8%20GW%20Medubi%20Power%20Station;>

middle of the day, CSP can help to meet demand peaks in the evening or late afternoon. CSP deployment, however, has lagged that of solar PV, with as of 2013 only 600 MW installed in both India and sub-Saharan Africa. Partly this reflects the burden of high upfront investment costs, as well as other constraints such as difficulties related to permitting, siting, and transmission interconnection.<sup>93</sup> Given best-in-class exposure to direct sunlight and rising costs of alternative generation, however, CSP will likely begin to scale in northwestern India and portions of sub-Saharan Africa within this decade.

Recognizing the limits of comparing the LCOE of different generation technologies (and, in particular, of comparing the costs of baseload versus variable generation), the above data points illustrate that the cost gap between coal and cleaner, renewable alternatives is rapidly closing.

**Figure 20: Projected LCOE for new-built PV and CSP (with storage) systems to 2050 (USD/MWh)**



*Note: Mid-points of the ranges below plotted on the graph*

	2013-15	2020	2025	2030	2035	2040	2045	2050
<b>India</b>								
Solar PV	87-137	67-105	50-78	42-66	38-61	36-57	32-51	31-48
CSP	146-213	116-169	96-124	86-112	72-105	69-101	66-96	64-94
<b>Africa</b>								
Solar PV	120-170	92-130	69-97	58-82	53-75	50-71	44-63	42-60
CSP	146-213	116-169	96-124	86-112	72-105	69-101	66-96	64-94

*Note: 2013-2015 solar PV estimate for India taken from BNEF and World Energy Council; estimate for Africa taken from CTI analysis of Kenyan cost data (range includes both ground-mounted and rooftop systems).*

*Projected cost reductions reflect rate of cost reductions (averaged across projections for utility-scale and rooftop systems) for solar PV in the IEA 2DS hi-Ren Scenario.*

*CSP values for both India and Africa reflects IEA's global range for 2015 new-built CSP plants in the IEA 2DS hi-Ren Scenario (assumes 8% discount rate).*

*Sources: BNEF and World Energy Council, IEA, CTI analysis 2014*

<sup>93</sup> See IEA, *ETP 2014*, Chapter 9, and IEA, and IEA, *Technology Roadmap: Solar Thermal Electricity - 2014 Edition*, 2014, 34-37.



**Conclusion: If LCOE is used as a comparison tool, wind power and solar PV are already approaching the cost per MWh of recent new coal plants. The scale of installations and pace of cost reductions for solar PV have outpaced most industry projections, and there is every change this trend could continue.**

### ***Internalizing environmental costs of coal - another upward pressure on coal-fired generation costs***

The negative health and environmental impacts of coal are well known. Impacts to air and water quality, human health, etc., however, generally are not reflected in the cost of coal-fired electricity. To take just one example, a 2005 study estimated the "true" all-in life-cycle cost of coal in the United States to be as high as \$150/MWh<sup>94</sup> (versus a current average LCOE for US conventional coal of \$95.6/MWh).<sup>95</sup> Most nations in sub-Saharan Africa and South Asia are ill-equipped to handle such impacts. Burning coal, for example, emits particulate matter emissions that are linked to increased prevalence of asthma and bronchitis, as well as an increase in the death rate from cardiovascular disease and respiratory ailments.<sup>96</sup> A recent air-sampling study, found PM2.5<sup>97</sup> levels in New Delhi to be twice as high as those in Beijing (and trending upward);<sup>98</sup> note that this is in a country that already has the world's highest death rate from chronic respiratory diseases and more deaths from asthma than any other nation.<sup>99</sup> More generally, a recent analysis by Yale University researchers identified seven of the 10 countries with the worst air pollution exposures in the world to be in South Asia.<sup>100</sup>

A tenet of the coal-energy access hypothesis is that "clean coal technologies provide the method to address access *as well as environmental concerns*" (emphasis added).<sup>101</sup> By making coal burn more efficiently, supercritical/ultra-supercritical and integrated gasification combined cycle (IGCC) technologies do indeed reduce air pollution from coal. The per-kW capital costs of these technologies, however, are 20-77% higher than for subcritical coal plants. Even with the benefit of more efficient coal burn, these higher capital costs can increase LCOE up to 20% above that of a subcritical coal plant.<sup>102</sup>

<sup>94</sup> Epstein, P.R., Buonocore, J. J., Eckerle, K., Hendryx, M., Stout III, B.M., et al., 2011, "Full cost accounting for the life cycle of coal," *Annals of the New York Academy of Sciences*, 1219(1). 73–98. DOI:10.1111/j.1749-6632.2010.05890. For more discussion, see Global Commission on the Economy and Climate, "New Climate Economy Report," Chapter 4, 3.2 Air pollution as a driver of energy system transformation.

<sup>95</sup> EIA, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014."

<sup>96</sup> US EPA, "PM 2.5: Objectives and History," <http://www.epa.gov/region4/sesd/pm25/p2.html>.

<sup>97</sup> This refers to particulate matter less than 2.5 micrometers in diameter, which is believed to pose the greatest health risk because it penetrates deeply into lungs.

<sup>98</sup> Gardiner Harris, "Beijing's Bad Air Would be Step up for Smoggy Delhi," *New York Times*, Jan 25, 2014, [http://www.nytimes.com/2014/01/26/world/asia/beijings-air-would-be-step-up-for-smoggy-delhi.html?\\_r=0](http://www.nytimes.com/2014/01/26/world/asia/beijings-air-would-be-step-up-for-smoggy-delhi.html?_r=0)

<sup>99</sup> World Health Organization, "Mortality: Chronic respiratory diseases, deaths per 100,000 – Data by Country," <http://apps.who.int/gho/data/node.main.A866?lang=en>

<sup>100</sup> Yale Center for Law and Environmental Policy, "2014 Environmental Performance Index: Air Quality," <http://www.epi.yale.edu/our-methods/air-quality>

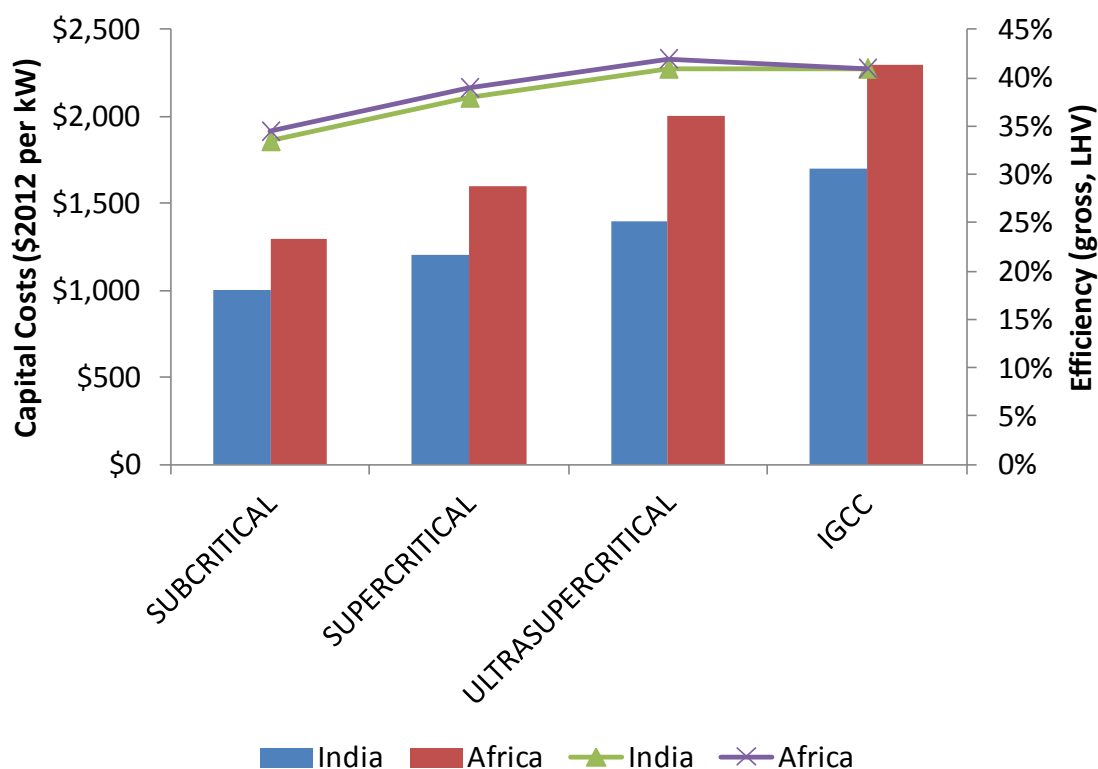
<sup>101</sup> Peabody Energy, 19.

<sup>102</sup> EIA, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014."



Though lack of data from commercial projects makes such estimates uncertain, equipping a plant to capture not just conventional pollutants but also carbon-dioxide (i.e. carbon capture and sequestration, or CCS) may increase LCOE up to 50% above that of a subcritical coal plant without CCS.<sup>103</sup>

Figure 21: Capital costs and plant efficiencies for different coal generation technologies



Note: LHV is lower heating value.  
Source: IEA, CTI/ETA analysis 2014

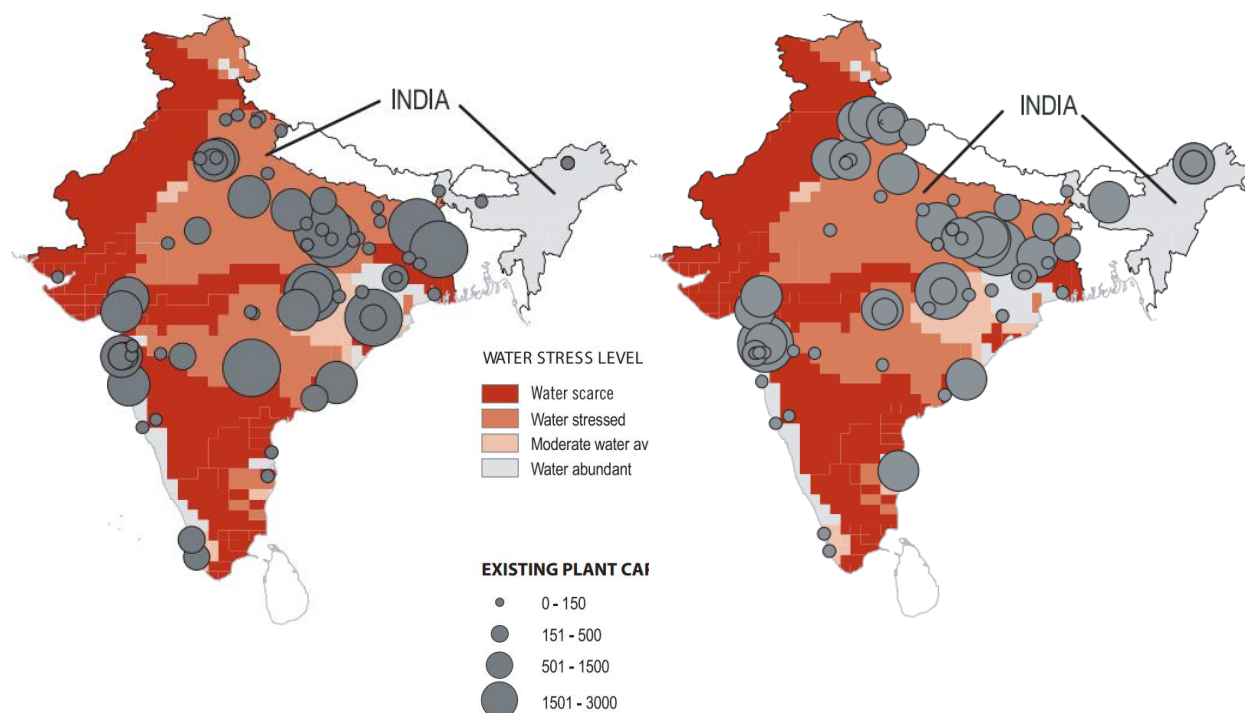
Coal's outside role in helping to industrialize the US, Europe, Japan and - more recently - China and nations of Southeast Asia has often involved heavy health and environmental costs. Inasmuch as nations of South Asia and sub-Saharan Africa invest in new coal plants, there is an urgent public health rationale for choosing the most advanced technologies. This relates not just to air pollution but also to efficient use of water, as coal-fired power plants use large amounts of water for steam production and cooling. For example, *nearly two-thirds of India's existing power generating capacity, (Figure 22) and 80% of planned capacity, (Figure 23) reside in "water-scarce or water-stressed areas."*<sup>104</sup>

<sup>103</sup> EIA, "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014."

<sup>104</sup> WRI, *Over heating: Financial risks from water constraints on power generation in Asia*, [http://www.wri.org/sites/default/files/pdf/over\\_heating\\_asia.pdf](http://www.wri.org/sites/default/files/pdf/over_heating_asia.pdf)

Figure 22: Existing power generating capacity and water stress levels

Figure 23: Planned power generating capacity and water stress levels



Source: WRI

In evaluating the potential for coal to expand power supplies with minimal environmental impact, there is a need to acknowledge how environmental-control measures will affect the cost of coal-fired plants and its economic competitiveness relative to other forms of generation.

**Conclusion: Internalizing the costs of preventing impacts on health, water and climate change through emissions limits, resource constraints or technological requirements will only increase the costs of continuing coal use.**

### ***Most energy-poor countries will struggle to finance coal-fired projects***

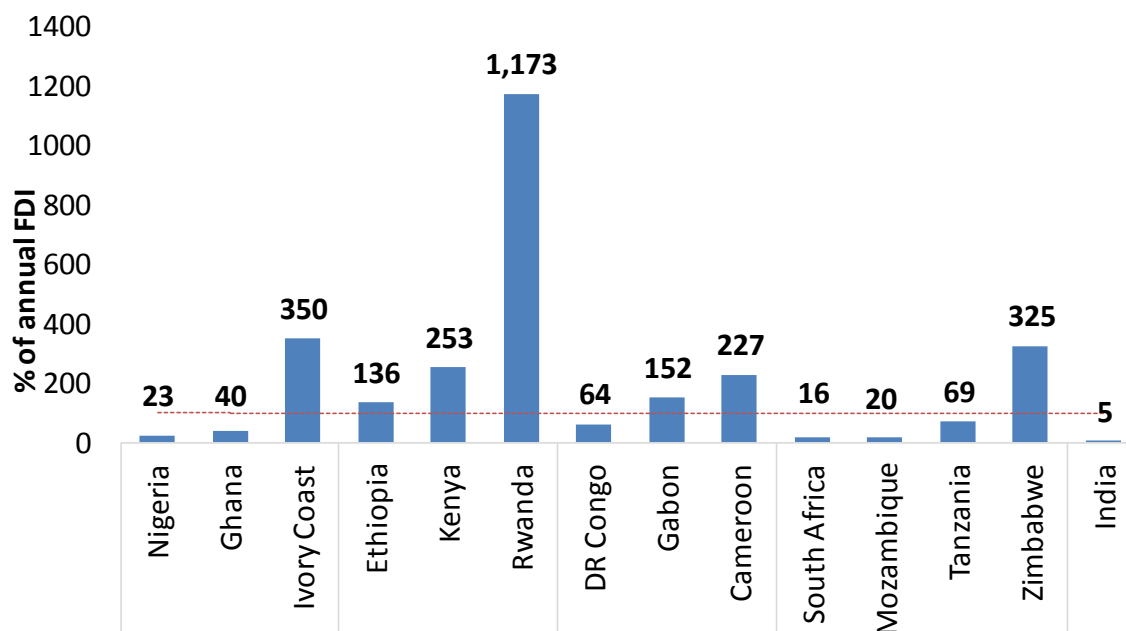
Even with an attractive \$/MWh cost and acceptable environmental impacts, the nature of coal-fired projects - large, centralized, and capital-intensive - will pose financing difficulties for many energy-poor countries. As with other forms of centralized generation, building larger plants generally enables coal plants to achieve a lower cost per MWh. Larger plant sizes, however, also increase required upfront investment - in the case of coal, beyond the financial means of many energy-poor countries.<sup>105</sup> For 2012, the IEA estimated the capital costs of a 1 GW coal-fired power plant to be \$1 billion for India and \$1.3 billion for Africa.<sup>106</sup>

<sup>105</sup> Note that this is also true of, for example, nuclear plants.

<sup>106</sup> IEA, "Power Generation in the New Policies and 450 Scenarios - Assumed investment costs, operation and maintenance costs and efficiencies in the IEA World Energy Investment Outlook 2014," Note that capital costs here exclude interest payments.

The figure below shows these costs as a portion of foreign direct investment (FDI) for India and a selection of countries in West, East, Central, and Southern Africa. Whereas India has demonstrated an ability to finance new coal-fired generation, the prospects for many of these African countries to finance a \$1.3 billion power plant range from dubious to preposterous.<sup>107</sup> Owing both to country risk dynamics as well as the preferences of multinational donors, few of these countries will be able to follow the recent example of South Africa, which financed its massive 4.8 MW Medupi plant in part via a \$3 billion World Bank loan (i.e. to cover one-third of total project costs).<sup>108</sup>

**Figure 24: Cost of 1 GW Coal-fired Power Plant as % of annual foreign direct investment (FDI)**



*Note: Steam coal, subcritical, \$1000/kW for India, \$1300/kW for Africa. Excludes financing-related costs.  
Source: IEA, World Bank, CTI/ETA analysis 2014*

There have been ongoing campaigns by civil society organizations to persuade international financial organizations such as development banks and export credit agencies to move away from financing fossil fuels. Recent announcements have indicated some shifts in positions; for example the World Bank announced that it will “only in rare circumstances” provide financial support for new greenfield coal power generation projects, such as “meeting basic energy needs in countries with no feasible alternatives.”<sup>109</sup> This position formed part of the World Bank’s new Energy Directions paper launched in 2013, which recognizes the need to “minimize the financial and environmental costs of expanding reliable energy supply”. This sits alongside the World Bank’s commitment to its Sustainable Energy for All initiative’s goals for 2030. This shift in public finance suggests it will be harder for new coal plants to access these sources of capital, which is likely to increase the cost of capital. Meanwhile the development banks reaffirmed their commitments to clean energy finance and have been leaders in the development and issuance of green bonds.<sup>110</sup>

<sup>107</sup> Note also that underdeveloped transmission infrastructure throughout Africa makes it currently unrealistic to expect a few relatively larger or richer countries to finance new coal-fired plants with the expectation of exporting the bulk of produced power to neighboring countries.

<sup>108</sup> The World Bank, “Eskom Investment Support Project,”

<http://www.worldbank.org/projects/P116410/eskom-investment-support-project?lang=en>.

<sup>109</sup> <http://www.worldbank.org/en/news/feature/2013/07/16/world-bank-group-direction-for-energy-sector>

<sup>110</sup> <http://www.eib.org/attachments/press/joint-mdb-statement-on-climate-finance.pdf>

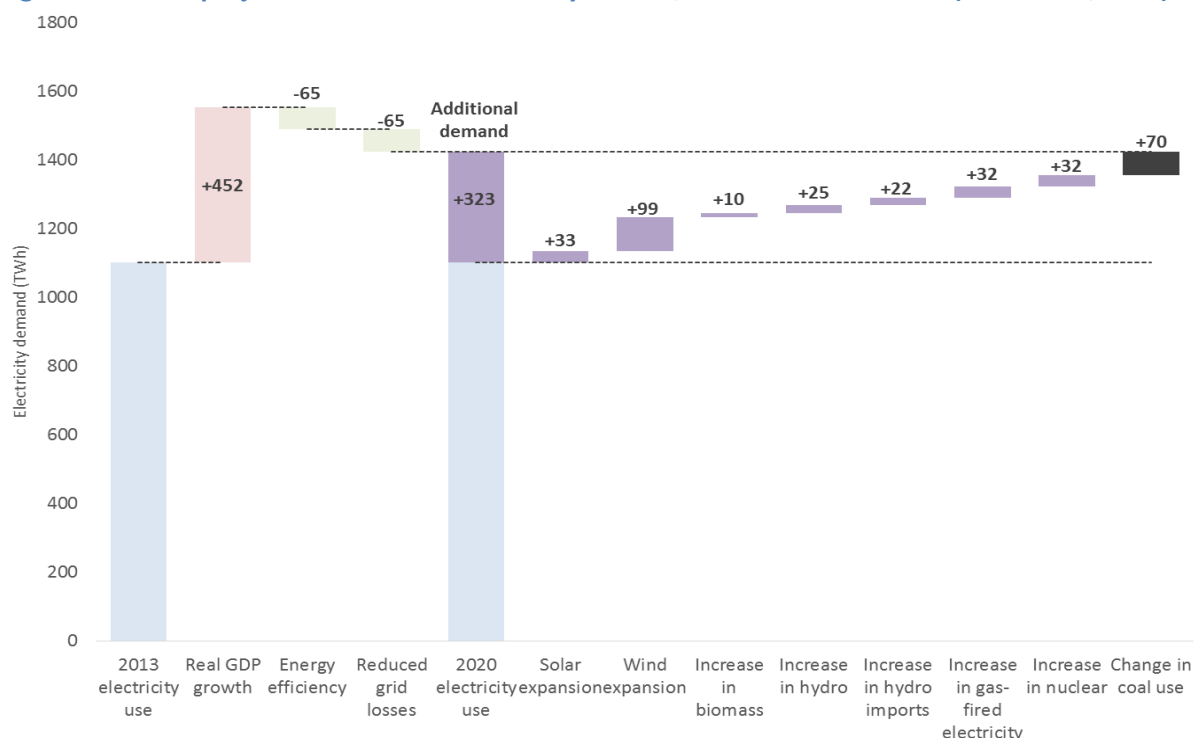
Even where they might involve higher per-kW upfront costs, the smaller, modular nature of renewable generation technologies such as onshore wind and distributed solar PV will often fit better than will coal with the financial realities of energy-poor countries. Given the urgency of increasing power supplies for these nations, this advantage should not be underestimated.

**Conclusion: Development finance is gearing more towards smaller scale renewables requirements in terms of both policy and financial products available.**

### ***Economic, environmental, and financial barriers likely to depress coal growth below NPS projections***

The constraints we survey above inform our view that - even without adoption of robust global climate policies - coal demand in South Asia and sub-Saharan Africa is unlikely to grow at the rates suggested by the IEA New Policies Scenario. In India, for example, we cite a recent forecast from the Institute for Energy Economics and Financial Analysis (IEEFA) for thermal coal demand to grow at a 2% CAGR through 2020 and a 1.2% CAGR from 2020-2035 (versus a 2011-2035 CAGR of 4.1% in the New Policies Scenario).<sup>111</sup> In 2011 coal supplied 68% (i.e. 715 TWh) of India's electricity demand; through 2020, however, IEEFA projects coal to satisfy only 16% (i.e. 70 TWh) of incremental Indian power demand, with the balance coming from advances in demand management and network efficiency and other generation technologies.

**Figure 25: IEEFA projection for India's electricity market, Production Waterfall (2013-2020, TWh)**



Source: IEEFA

<sup>111</sup> CTI and IEEFA, *Thermal coal demand: comparing projections and examining risks*, 52.

IEEFA forecasts a similar trend for South Africa, with coal through 2020 supplying only 28% of incremental power demand (i.e. 11 TWh). These projections suggest that - even in nations with extensive existing coal-fired generation and ample coal resources - advances in energy efficiency and renewable energy are enabling power expansion pathways that involve relatively little new coal use. Our next section explores this topic in more detail.

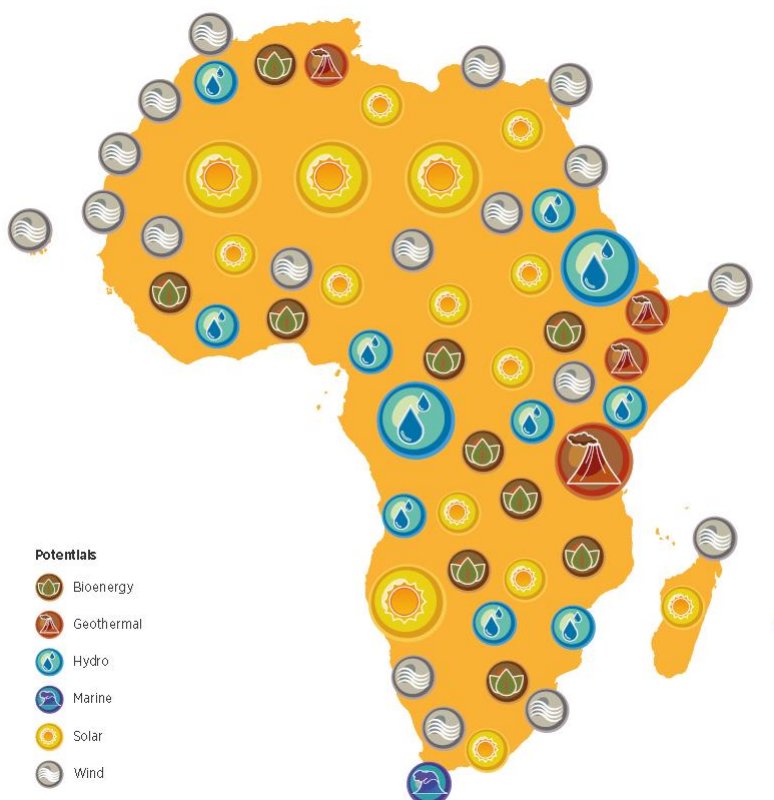
**Conclusion: It is important to continually test assumptions on the fundamentals of demand, as technological innovation and economic growth forecasts are difficult to accurately predict.**

## Alternative pathways for India and Africa: 2DS Hi-Renewables Scenario

Economic development in both India and sub-Saharan Africa urgently requires improvement of national power supplies. A key resource that these regions have to achieve this task is a tremendous (and largely untapped) potential to generate electricity from low-carbon renewable sources. In April 2014 the Indian Planning Commission published a report forecasting a tripling of wind, solar and biomass share of electricity generation to 18% by 2030, taking wind capacity to 120GW and solar to 100GW.<sup>112</sup> Charting an even more ambitious course, former US Department of Energy official Darshan Goswami recently published an op-ed titled “Can India Achieve 100% Renewable Energy?”<sup>113</sup> Goswami notes that “taking advantage of 300-330 sunny days a year, India could easily generate 5000 trillion kWh of solar energy, which is higher than India’s total yearly energy consumption. Even if a tenth of this potential was utilized, it could mark the end of India’s power problems.” With potential for 1,000GW of solar across India’s deserts, canal systems, water-pumps and farmlands, 170GW of potential offshore wind farms, 148GW of hydro and 10GW of geothermal potential, there remains huge scope to lift India’s renewable energy ambitions.

Like India, Africa also has rich potential for renewable energy generation, with major resources for hydroelectric generation (central, east, and southern Africa), solar (north and southern Africa), wind (north, southern, and east Africa), bioenergy (west, central, and southern Africa), and geothermal (east Africa). As of 2013, almost half of African nations had done national assessments of renewable resources.

Figure 26: Distribution of identified renewable energy potential in Africa



Source: IRENA analysis based on the Global Atlas

<sup>112</sup> Jairam Ramesh, “Germany’s great green gamble.”

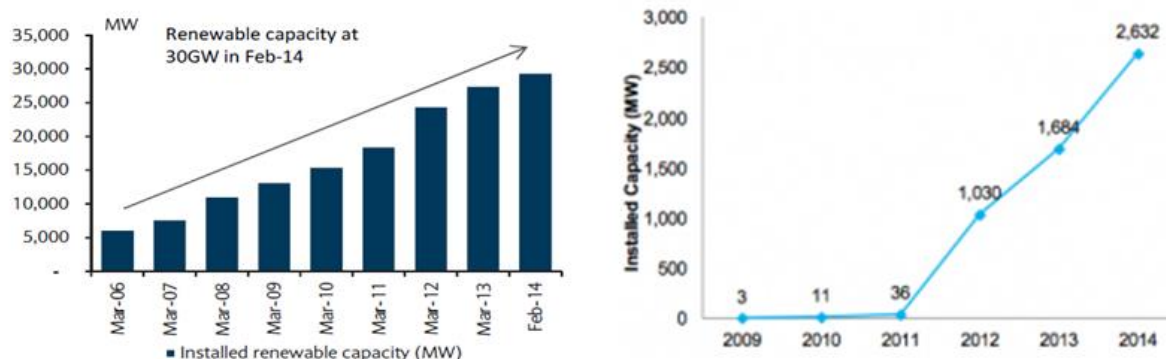
<sup>113</sup> Darshan Goswami, “Can India Achieve 100% Renewable Energy?”, Aug 21 2014, *CleanTechnica*, <http://cleantechnica.com/2014/08/21/can-india-achieve-100-renewable-energy-future/>

### Renewable electricity sources in India and Africa growing rapidly

The sun, wind, and waves that underpin potential energy generation in Africa and India have existed for millennia. What is more significant is the actions that India and African nations have recently taken to *harness* these resources as a means to grow, diversify, and clean up national energy supplies. From a base of about 5 GW in March 2006, India had as of February 2014 increased its installed renewable generating capacity to 30 GW, with a goal of 72 GW by 2022. Though the bulk of this growth came from wind power (21 GW of installed capacity as of March 2014), India has also seen tremendous growth in solar power. India's National Solar Mission program has helped install solar capacity to grow from less than 1 GW in 2011 to 2.6 GW in 2014 (with a target of 34 GW by 2022).<sup>114</sup>

Several Indian States have announced utility solar project targets of 1-4GW each, including Andhra Pradesh and Telagana. Facing a coal deficit at its thermal power plants, the state of Punjab has announced plans to install 2 GW of utility-scale solar projects, including 100 MW of rooftop PV projects; to wit, Punjab recently completed 7.52 MW rooftop PV array that is now the world's largest rooftop solar installation.<sup>115</sup> *Reflecting solar momentum on the subcontinent, Coal India (one of the world's largest coal mining companies) is evaluating the possibility to invest \$1.2 billion in the development of 1000 MW of solar power plants.*<sup>116</sup>

**Figure 27: India has added 25,000 MW of renewable generation since 2006 (lhs), including 2.5 GW of solar PV (rhs)**



Source: CEA, Barclay's Research Mar'2014, Deutsche Bank, MNRE

Sub-Saharan Africa has also seen accelerating installation of renewable energy. Since August 2011, South Africa's REIPPPP program has added nearly 4,000 MW of renewable generating capacity (mostly wind and solar PV) via a process that has been praised for its transparency and cost-effectiveness.<sup>117</sup> Hydropower heavyweight Ethiopia also has Africa's largest wind farm and is

<sup>114</sup> Lanco Infratech Annual Report 2013/14, 19, quoting Government of India, Ministry of New and Renewable Energy.

<sup>115</sup> Mridul Chadha, "World's Largest Single Rooftop Solar Power Project Commissioned in India," *CleanTechnica*, Sep 12 2014, <http://cleantechnica.com/2014/09/12/worlds-largest-single-rooftop-solar-power-project-commissioned-india/>

<sup>116</sup> Mridul Chadha, "World's Largest Coal Miner to Invest \$1.2 billion in Solar," *CleanTechnica*, Sep 24 2014, <http://cleantechnica.com/2014/09/24/worlds-largest-coal-miner-invest-1-2-billion-solar-power/>

<sup>117</sup> Anton Eberhard, Joel Kolker, and James Leigland, "South Africa's Renewable Energy IPP Procurement Program:



pursuing geothermal energy and off-grid renewable solutions. From a 2010 base of 40 MW of mostly small-scale solar PV, sub-Saharan Africa had by 2013 installed roughly 280 MW of solar generating capacity, including a few utility-scale PV and CSP plants.<sup>118</sup> Major grid-connected PV projects under construction include 150 MW of projects in South Africa, the 155 MW Nzema plant in Ghana, and proposals for ~100 MW projects in Ethiopia, Nigeria, Sudan, and Mozambique.

Recent action in India and Africa reflects how the center of gravity for renewable electricity is shifting to the developing world. According to a recent Climatescope study of 55 emerging economies (including India and multiple nations in sub-Saharan Africa),<sup>119</sup> from 2008-2013 this group installed a combined 142 GW of renewable generating capacity. From 2007-2013 annual renewable investment in these countries more than doubled from \$59.3 billion to \$122 billion. For the purpose of this discussion, it is also relevant that - in Climatescope's assessment of the investment climate and policies related to clean energy in these 55 countries - the "top 10" countries included India as well as South Africa, Kenya, and Uganda.

**Conclusion: There is significant potential for renewables expansion in India and Sub-Saharan Africa. Installations are now growing rapidly and outpacing previous forecasts.**

### **IEA 2DS hi-Ren Scenario**

*The above paragraphs outline the outstanding renewable generation potential of Africa and India and demonstrated recent progress in harnessing this potential. This suggests the possibility for India and Africa to attain the same level of economic development as in the New Policies Scenario with far less reliance on coal (and consequent CO<sub>2</sub> emissions). The IEA's 2°C high-Renewables Scenario (hi-Ren Scenario), in which energy systems rapidly transform to "achieve the goal of limiting the global mean temperature increase to 2°C,"<sup>120</sup> demonstrates what a renewable electricity future could mean for these regions. In this scenario, by 2050 less than 5% of electricity generation is coming from coal in both India and Africa (versus, in 2011, 68% of India's electricity and 38% of Africa's electricity coming from coal). In place of generation from coal and other fossil fuels, in the hi-Ren Scenario by 2050 both India and Africa are generating more than 80% of their electricity from low-*

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Success Factors and Lessons," May 2014, <http://www.gsb.uct.ac.za/files/PPIAFReport.pdf>.

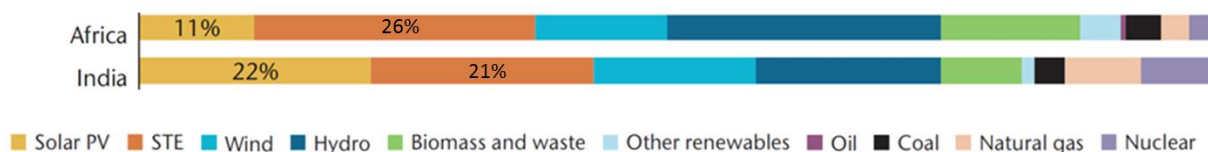
<sup>118</sup> IEA, *Africa Energy Outlook*, 58.

<sup>119</sup> The Multilateral Investment Fund, UK Department for International Development, Power Africa, and BNEF, *Climatescope 2014: Mapping the Global Frontiers of Clean Energy Investment*, Oct 2014, <http://global-climatescope.org/en/download/reports/climatescope-2014-report-en.pdf>

<sup>120</sup> The IEA (*ETP 2014*, Box 1.1) notes that 2°C Scenario (2DS) "sees energy systems radically transformed to achieve the goal of limiting the global mean temperature increase to 2°C. The high-renewables Scenario (hi-Ren Scenario), achieves the target with a larger share of renewables, which requires faster and stronger deployment of PV, wind power and STE, to compensate for the assumed slower progress in the development of CCS and deployment of nuclear than in 2DS. Note that, through 2035, the 2DS is consistent with the 450 Scenario. The ETP 2014 analysis is based on a bottom-up TIMES\* model that uses cost optimization to identify least-cost mixes of energy technologies and fuels to meet energy demand, given constraints such as the availability of natural resources. Covering 28 world regions, the model permits the analysis of fuel and technology choices throughout the energy system, representing about 1 000 individual technologies. It has been developed over several years and used in many analyses of the global energy sector. The ETP model is supplemented with detailed demand-side models for all major end-uses in the industry, buildings and transport sectors. \* TIMES = The Integrated MARKAL (Market Allocation)-EFOM (energy flow optimization model) System."

carbon renewable sources (versus roughly 17% in 2011); the dominant portion of this comes from solar energy - from both PV installations and concentrating solar power (CSP) plants – which in each region accounts for roughly 40% of total 2050 electricity generation.

**Figure 28: Electricity generation by fuel source in hi-Ren scenario, 2050**

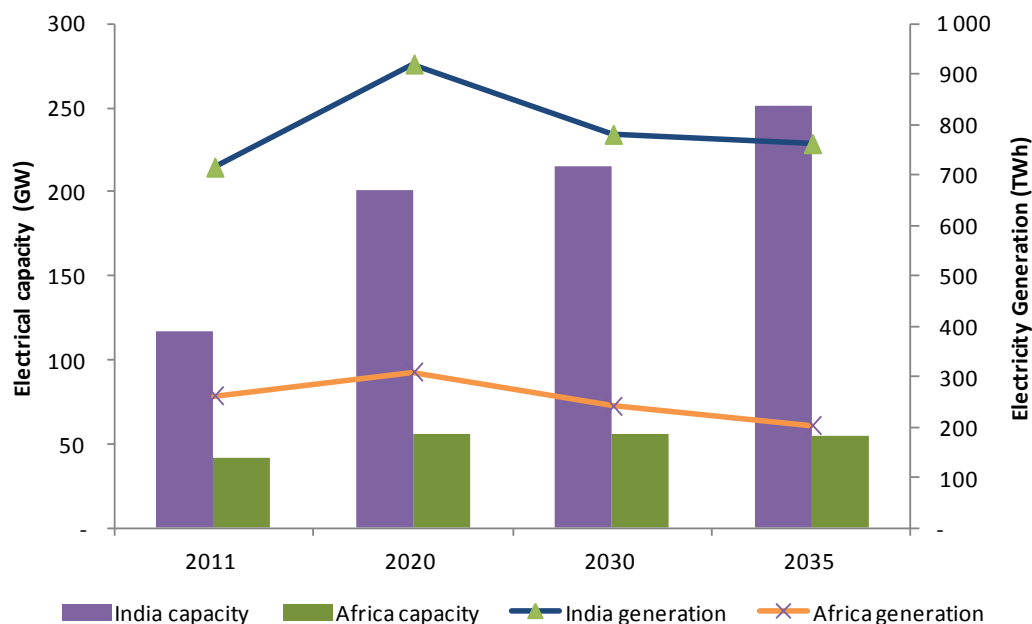


Note: STE is solar thermal electricity, referred to elsewhere in this document as CSP (concentrating solar power)

Source: IEA, CTI/ETA analysis 2014

Though the IEA does not publish detailed regional pathways for its hi-Ren Scenario, it is possible to roughly analyze the trajectory for coal demand in such a scenario by examining projections in the IEA's 450 Scenario, which is broadly consistent with the 2DS through 2035, (for further explanation of the relationship between these scenarios see footnote below or IEA website).<sup>121</sup> In these projections, coal-fired generation in both India and Africa peaks around 2020 and then declines, with 2035 generation in each case being roughly equal to the 2011 level. In the 450 Scenario by 2035, coal's share of the overall electricity mix has declined to 26% in India and 16% in Africa (compared with, in the New Policies Scenario, 56% for India and 26% for Africa).

**Figure 29: India and Africa coal-fired electrical capacity and electricity generation in 450 Scenario, 2011-2035**



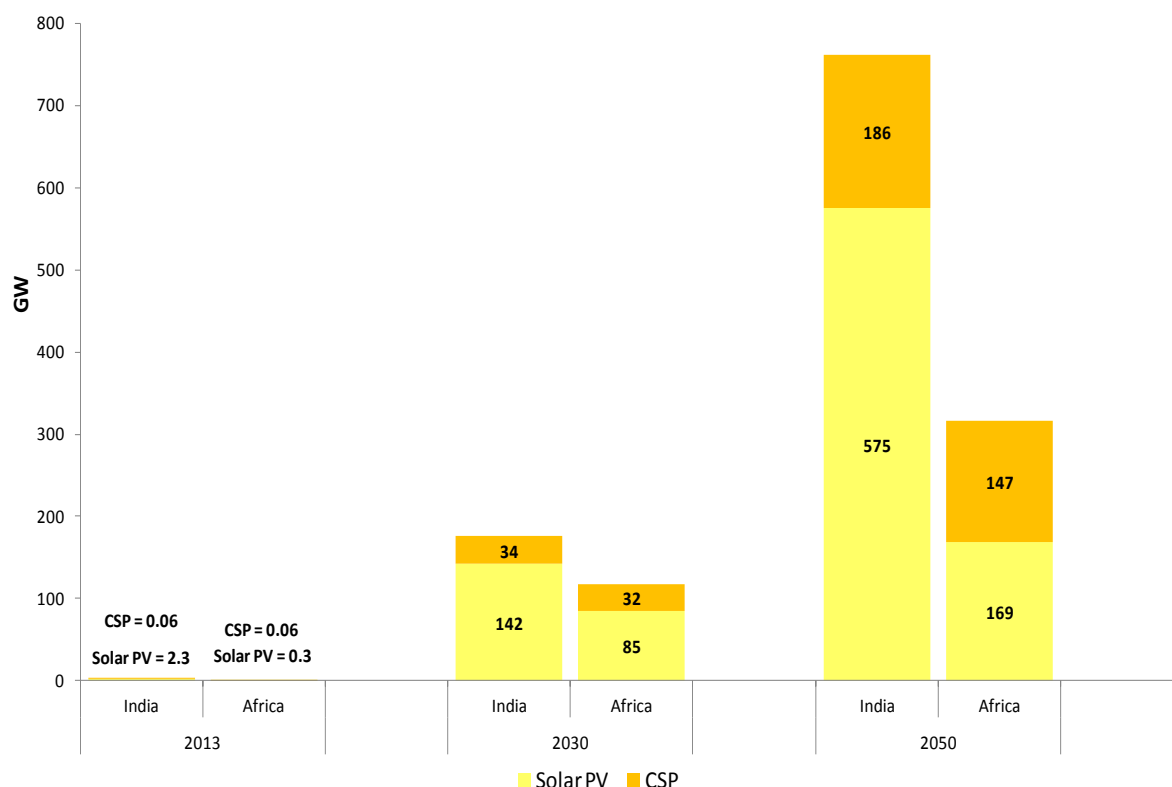
Source: IEA, CTI/ETA analysis 2014

<sup>121</sup> Recall that hi-Ren is a variant of the IEA's 2DS Scenario. Because the hi-Ren scenario sees reduced deployment of CCS, the 450 Scenario numbers will likely overstate coal demand in such a scenario to some degree. Also, note that IEA analyses suggest that for every 1GW of new fossil capacity, 3GW must immediately close in order to stay within 2DS. This suggests that every GW of new coal-fired capacity in India or Africa must require 3GW to close somewhere else.

As opposed to the limited growth in coal-fired generation and capacity, a hi-Ren Scenario sees robust deployment of both solar PV and concentrating solar power (CSP) technologies, which are grid-tied solutions. From a combined capacity of less than 3 GW of solar PV and CSP across both India and Africa in 2013, rapid deployment of these technologies increase the combined solar capacity in these two regions to nearly 300 GW by 2030 and over 1000 GW by 2050.

Deployment of solar PV benefits from continued cost reductions (discussed more below). Projected deployment of CSP is aided by the very favorable direct sunlight resources of sub-Saharan Africa and northwest India. Note that the value of CSP increases as PV is deployed in large amounts. This is because CSP projects can use various thermal storage media (e.g. molten salts) to make their output "dispatchable," hence enhancing their value to grid operators. This storage ability makes CSP a useful complement to solar PV; whereas PV output peaks in the middle of the day, CSP can help to meet demand peaks in the evening or late afternoon. Though the growth trajectories are less dramatic, other renewable electricity sources such as wind power, hydropower, and geothermal also see significant capacity expansion in the hi-Ren Scenario.

Figure 30: Deployment of solar PV and CSP in India and Africa in hi-Ren Scenario, 2013-2050



Source: IEA, CTI/ETA analysis 2014

**Conclusion: The IEA has a range of scenarios addressing the potential for renewables and energy access – these objectives need to be central to developing a sustainable energy future. Considering these potential scenarios is a sound risk management strategy, rather than selectively looking at the IEA's "New Policies" or "Current Policies" scenarios, in which neither climate change nor energy access is effectively addressed.**

### ***Investment requirements for a 2DS hi-Ren scenario***

Achieving the future energy mix outlined in the hi-Ren Scenario will not come about without additional investment. Building a central system as we have discussed is not going to relieve energy poverty in rural areas, and of course itself requires capital investment. But renewable energy requires more capital upfront which is then compensated for by lower running costs. The IEA analyzes the investments required for a hi-Ren Scenario by comparing them with the investments required under a scenario – the 6DS<sup>122</sup> – in which controlling carbon emissions is not a priority and fossil fuel dominance of the global energy system continues over the next several decades; and energy poverty is not fully tackled in rural areas. Analyzing these investment requirements at a regional level is complicated due to the IEA data grouping “Africa and the Middle East” into a single region. In the 450 Scenario, however – which is roughly consistent with a 2DS Scenario through 2035 – from 2011-2035 Africa and the Middle East add roughly the same amount of electrical capacity. We therefore make the rough assumption that, for figures in the 2DS hi-Ren Scenario for “Africa and the Middle East,” roughly half of cumulative investment will occur in Africa and half in the Middle East. Though lacking complete precision, this simplification is useful to give a rough sense of the investments required to put Africa and the India onto a path toward low-carbon electricity systems.

On a 6DS pathway, through 2050 India and Africa are projected to invest roughly \$4.1 trillion in the power sector (in 2012 dollars); this equates to annual average investment of \$100 billion per year – though, it should be noted, required investment will rise significantly over time (i.e. making required annual investment through, say, 2020, substantially less than \$100 billion). To transition from a 6DS to a 2DS hi-Ren scenario, average annual power sector investment must increase by roughly \$65 billion (i.e. to \$165 billion) – again this is not the energy access for all. This additional investment, however, is projected to yield significant future savings in the form of reduced expenditures on coal, oil, and gas. *As a result of trillions in cumulative fuel savings, globally through 2050 the hi-Ren Scenario increases the total cumulative costs of power generation (i.e. investment costs plus fuel costs) increase by only 1% relative to the 6DS.*<sup>123</sup> As fuel costs for African and Indian power plants are often among the highest in the world, there is little basis to expect that the power-sector net profile of the hi-Ren Scenario will be less favorable in these regions than at the global level. Further our view is generally more positive on the outlook for renewable energy costs over time, leaving the possibility that Hi-Ren is a cheaper option in the end.

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<sup>122</sup> The IEA (*ETP 2014*, Box 1.1) notes that “6DS is largely an extension of current trends. By 2050, energy use grows by more than two-thirds (compared with 2011) and total GHG emissions rise even more. In the absence of efforts to stabilize atmospheric concentrations of GHGs, average global temperature rise is projected to be at least 6 degree C in the long term. The 6DS is broadly consistent with the World Energy Outlook (WEO) Current Policy Scenario through 2035.”

<sup>123</sup> IEA, *Technology Roadmap: Solar Photovoltaic Energy - 2014 Edition*, 26. The IEA does not analyze projected fuel savings in the 2DS hi-Ren Scenario at different discount rates or taking into account changes in fuel prices as a result of reduced demand. Applying a high discount rate to future fuel savings will reduce their present value (i.e. increase net additional system costs in the hi-Ren Scenario relative to the 6DS), whereas taking price changes into account will increase their present value (i.e. reduce net additional system costs in the hi-Ren Scenario relative to the 6DS),

**Table 6: Power-sector investments needs for India and Africa in the 6DS and 2DS hi-Ren, 2011-2050 (USD trillion)**

	2011-2050		Avg. annual investments	
	6DS	2DS-hi-Ren	6DS	2DS-hi-Ren
India	2.5	4.3	0.06	0.11
Africa*	1.6	2.4	0.04	0.06
<b>Total</b>	<b>4.1</b>	<b>6.7</b>	<b>0.10</b>	<b>0.17</b>

\*IEA regional unit is "Middle East and Africa." Figures are CTI/ETA estimates based on IEA 2014 global projections.  
Source: IEA, CTI/ETA analysis 2014

Even with a minimal or positive long-term cost impact, however, funding investments in capital-intensive technologies is always challenging. Annual additional power-sector up front investments for a hi-Ren Scenario – which, it bears repeating, rise significantly over time – equates to an annual per capita contribution of \$37 in India and \$16 in Africa. In India, this amount equates to 2.5% of 2013 per-capita GDP; in Africa, the relative comparison ranges from 0.1% (for Gabon) to 6% (for Burundi). Through 2050, as incomes in these regions rise, these percentages will decline accordingly. For comparison, as a result of limited access to modern energy sources, households in India and sub-Saharan Africa currently spend anywhere from 6-14% of household income on all forms of energy (i.e. electricity, cooking fuels, etc.).<sup>124</sup>

**Table 7: Annual per capita additional power-sector investments in the 2DS hi-Ren (relative to the 6DS), 2011-2050**

	Annual per capita (USD)	% of 2013 GDP per capita
India	37	2.5%
Africa*	16	0.1-6.0%

\*IEA regional unit is "Middle East and Africa." Figures are CTI/ETA estimates based on IEA 2014 global projections.  
Source: IEA, CTI/ETA analysis 2014

Whatever the exact required investments as a share of current per-capita income, for many countries finding the upfront capital to fund a transition to low-carbon electricity sources may be challenging. This highlights the importance of international efforts to increase climate finance for developing countries. For example, as part of the 2010 Cancun Agreements, developed countries pledged to increase funding for climate change mitigation and adaption in developing countries to \$100 billion per year by 2020 from a mix of public and private sources.<sup>125</sup> The \$65 billion in annual required clean energy investment for Africa and India ought to be key priority for how such funds are used. Required additional investments in the 2DS hi-Ren Scenario also underscore the potential impact of financial (i.e. solar lease) and business model (i.e. local manufacturing) innovations to lower the costs of clean energy deployment - a topic discussed in more detail below.

<sup>124</sup> World Health Organization (WHO), "Household Energy and the Millennium Development Goals," <http://www.who.int/indoorair/publications/fflsection2.pdf>

<sup>125</sup> <http://cancun.unfccc.int/financial-technology-and-capacity-building-support/new-long-term-funding-arrangements/> Since formalizing the Cancun Agreements, developed countries have fulfilled a "fast start finance" commitment to provide more than \$30 billion in new and additional public resources for climate action.  
[http://unfccc.int/files/documentation/submissions\\_from\\_parties/application/pdf/cop\\_suf\\_usa\\_07102013.pdf](http://unfccc.int/files/documentation/submissions_from_parties/application/pdf/cop_suf_usa_07102013.pdf)

**Conclusion: While the costs of a high renewable pathway are seen by the IEA to be similar to, or in our view could turn out to be cheaper than, centralized coal power, especially if the goal is expanded to include energy access for all, there are higher up front capital costs. This points to the importance of support from developed countries on the finance front.**

## Commercial sector will be critical early adopter of clean energy technologies

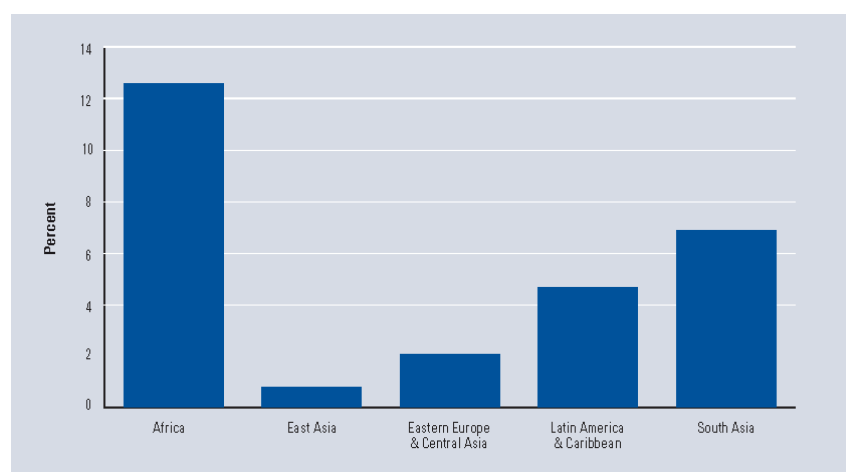
Delivering growing economies will require increasing investment in all forms of low-carbon renewable generation: solar PV, CSP, wind power, hydropower, biomass, geothermal, etc. In the context of the present power systems of India and sub-Saharan Africa, however, there are unique opportunities for solar PV (in particular distributed solar PV) to make energy supplies more reliable and affordable. Even for areas currently connected to the grid and equipped with basic energy services, moving toward an affordable and reliable power supply is the other key dimension of the energy access debate. Briefly reviewing the problems of reliability and affordability in the power sectors of these regions will help to illustrate this point.

### **Unreliable power supplies are a major drag on businesses in India and Africa**

Discussion above noted that transmission and distribution losses across both India and sub-Saharan Africa average roughly 20% (i.e. three times the level in the US and China). This illustrates one of the costliest problems facing businesses in these regions: low-quality and unreliable power supplies. With respect to Africa, for example, economists at the World Bank observe that:

*“Firms around the world experience power outages that last from few minutes to hours. Africa holds the unenviable record of being one of the worst places, experiencing the longest outages. In some countries in the continent, power losses last approximately 12 hours. As a consequence, firms in Africa lose power, on average, for 13 percent of their working hours. This is much higher than in all other regions. In East Asia, for example, firms lose power for only 1 percent of their working hours. South Asia is the region closest to Africa, and yet firms there lose power for only 7 percent of the working hours.”<sup>126</sup>*

**Figure 31: Share of working hours lost due to power outages**



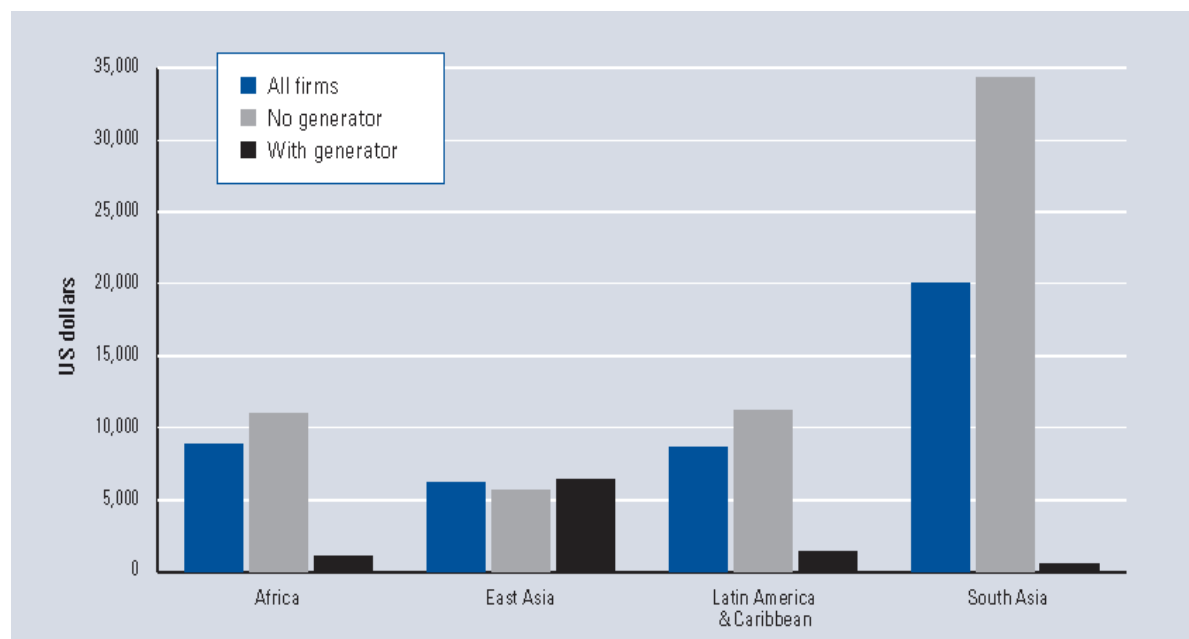
Source: Iarossi calculations using data from World Bank Enterprise Surveys (various years).

<sup>126</sup> GIUSEPPE IAROSSI, “Benchmarking Africa’s Costs and Competitiveness”, Chapter 4 in *The Africa Competitiveness Report 2009*, The World Bank, 2009, <http://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Africa%20Competitiveness%20Report%202009.pdf> For sub-Saharan Africa, the IEA estimates that grid-based electricity is unavailable for 540 hours on average (6% of the year), with this percentage being much higher in countries such as Nigeria, Guinea and the Central African Republic. IEA, *Africa Energy Outlook*, 42.



Loss of working hours due to power outages has significant economic costs. In Nigeria, for example, estimates for the marginal cost of power outages range from \$0.94 to \$3.13 per kWh of lost electricity.<sup>127</sup> African firms on average loss nearly \$9,000 annually due to unreliable power supplies; in South Asia, average power-related economic losses are more than double this amount.<sup>128</sup>

**Figure 32: Estimated electricity losses (total, with and without generator)**



Source: IAROSSI calculations using data from World Bank Enterprise Surveys (various years).

Chronically unreliable power supplies have prompted firms in Africa and South Asia to invest heavily in on-site generation. World Bank surveys indicate that the percentage of firms owning on-site generation is 38% in Africa (60% for export-focused firms) and 50% in South Asia. The dominant technology for on-site power supply is diesel generators, with capacities ranging from 1-5 MW (for small and medium-sized firms) and up to several hundred MW for large firms. For sub-Saharan Africa in 2012, the IEA estimates that 16 TWh of electricity demand was met by back-up generators, with more than 80% of this going to service and industrial firms (principally located in Nigeria).<sup>129</sup> The IEA notes this estimate to imply that "total electricity supply was around 3% higher than reported and that around 90 kb/d of oil was used to generate the additional electricity, at an estimated cost of over \$5 billion."<sup>130</sup>

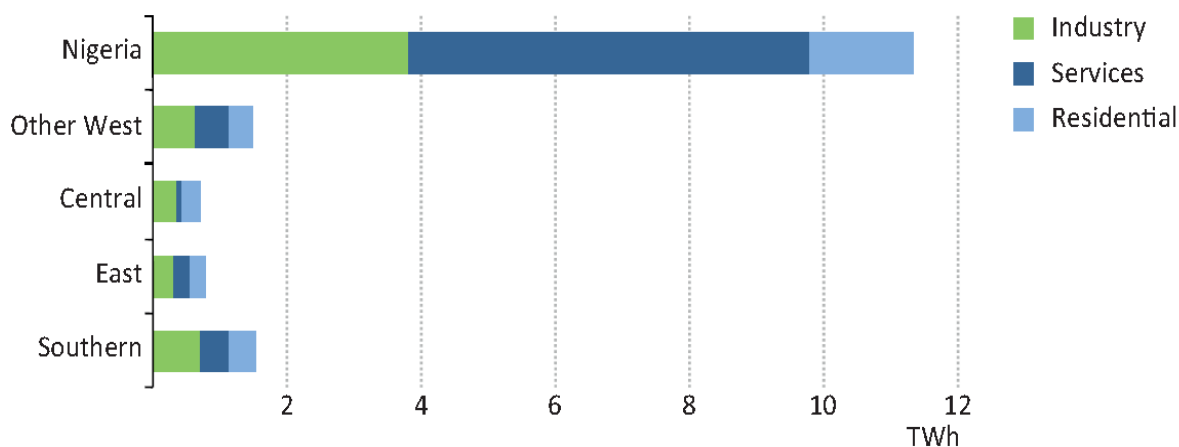
<sup>127</sup> Adeola Adenikinju, "Analysis of the cost of infrastructure failures in a developing economy: The case of the electricity sector in Nigeria," Department of Economics and Centre for Economics and Allied Research University of Ibadan, *AERC Research Paper 148*, African Economic Research Consortium, Nairobi February 2005 <http://dspace.africaportal.org/jspui/bitstream/123456789/32040/1/RP148.pdf?1>

<sup>128</sup> IAROSSI, "Benchmarking Africa's Costs and Competitiveness."

<sup>129</sup> IEA estimate based on fuel consumption data from CITAC and World Bank Enterprise Surveys.

<sup>130</sup> IEA, *Africa Energy Outlook*, 42.

Figure 33: African electricity demand met by back-up generators by sub-region, 2012



Source: IEA analysis and estimates.

\$5 billion for annual on-site generation costs represents an economic burden on the business sector in sub-Saharan Africa. This results from the very high cost of diesel generation; \$5 billion for 16 TWh of electricity suggests an average cost of \$310/MWh, which is right in the middle of the IEA's estimated range for diesel-generated electricity in sub-Saharan Africa of roughly \$255/MWh (assuming a diesel price of \$0.75/liter) to \$330/MWh (assuming a diesel price of \$1/liter).<sup>131</sup> The high costs that businesses currently pay to ensure stable power supplies creates opportunities for more affordable renewable solutions.

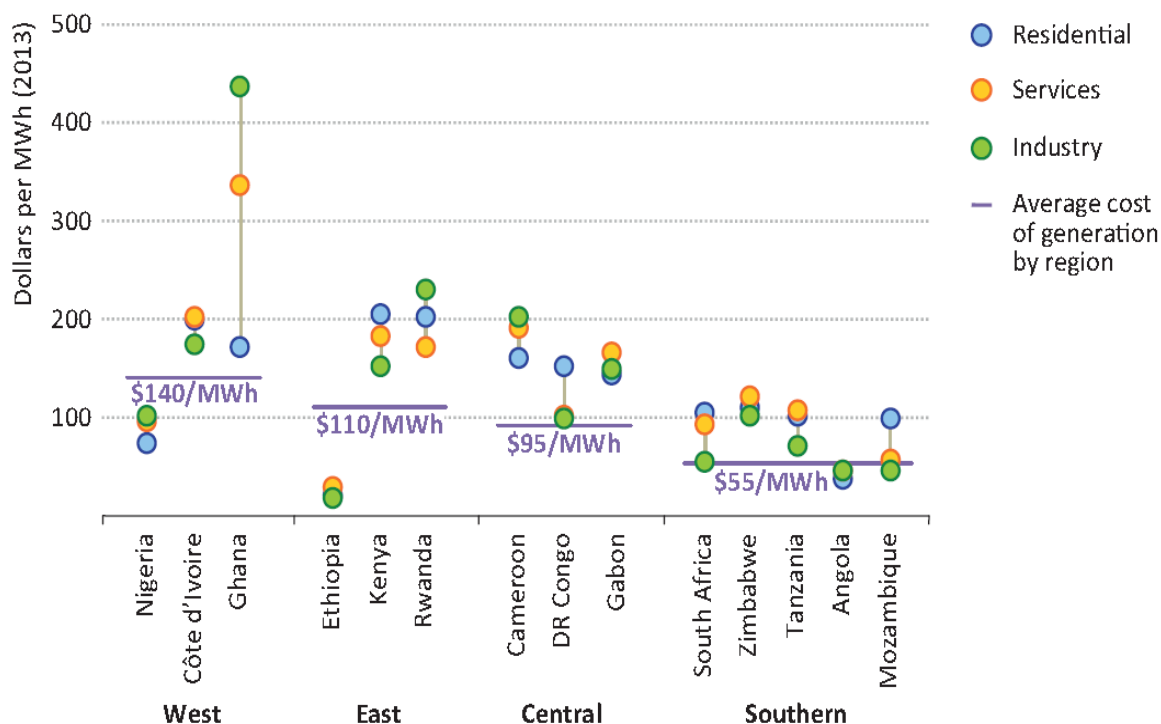
### ***Even where power is available, it is often too expensive***

Where businesses and households in sub-Saharan Africa are able to access power from the grid, they often do so at a high cost. For example, with average tariffs between \$130-140/MWh, the IEA observes that electricity tariffs in sub-Saharan Africa "are in many instances among the highest anywhere in the world."<sup>132</sup> Tariffs paid by commercial and industrial customers generally exceed those paid by residential customers, and near or exceed \$200/MWh in Cote d'Ivoire, Ghana, Kenya, Rwanda, and Cameroon. Moreover, even at levels that are high by international standards, in many sub-Saharan African countries tariffs "do not fully reflect the cost of electricity supply" - incorporating additional costs "such as those relating to T&D losses, T&D investment and retail can add \$60-\$100 per MWh to the total cost of electricity supply." *In other words, this suggests that average electricity tariffs in sub-Saharan Africa - if set to enable full cost recovery - would be closer to \$190-\$220/MWh.*

<sup>131</sup> IEA, *Africa Energy Outlook*, Figure 1.25, 58.

<sup>132</sup> IEA, *Africa Energy Outlook*, 66. In comparison, electricity tariffs in Latin America, Eastern Europe and East Asia are around \$80/MWh.

Figure 34: Grid electricity prices by end-use sector in selected sub-Saharan African countries, 2012



Source: IEA

**Conclusion: The electricity grids of Africa and India suffer from significant reliability issues. Disruptions due to unreliable grid-based electricity – and the high cost of on-site diesel generation – create significant economic opportunities for distributed clean energy technologies.**

### **High costs of diesel-generated and grid electricity enhance economics of distributed renewables**

Combined with the high cost of diesel-generated electricity, high electricity tariffs for commercial and industrial customers enhance the economic attractiveness of using solar PV and other distributed technologies in order to offset on-site loads. Moreover, the cost of electricity from such systems is now competitive with retail tariffs in multiple countries of West, East, and Central Africa.

**Table 8: Indicate levelized cost of electricity (LCOE) for off-grid technologies in sub-Saharan Africa (USD/MWh)**

	IEA	European Commission	CTI analysis	SMA Solar Technology
Diesel generator	255-335*	37-3,000**		
Solar PV (small)	305		120-170***	
Small hydro	270			
Small wind	260			
Hybrid diesel-PV-battery systems (300 kW to 1 MW)				270-450
Average retail tariff	130-140			

Note: IEA estimates, most recent available, are for 2012; continued decline in solar PV system costs from 2012-2014 may explain difference between IEA and CTI estimates.

\*Assumes diesel prices of \$0.75-1/liter.

\*\* Reflects full range across Africa for diesel prices of less than \$0.50/liter (in countries with high fuel subsidies) to greater than \$4.00/liter (in remote regions). Converted to USD at a rate of 1 EUR = 1.25 USD.

\*\*\* Reflects latest cost data for Kenya and assumes 9% discount rate; at a 5% discount rate the LCOE range would be reduced to \$110-120/MWh. Lower-bound for rooftop systems would be \$150/MWh.

Sources: IEA, European Commission, SMA Solar Technology, CTI analysis 2014

In Kenya, for example, review of proprietary industry sources as of Fall 2014 suggests installed costs for commercial rooftop projects of \$1.80-\$2.00/W, and for larger (i.e. 2 MW+) ground-mounted arrays as low as \$1.50/W.<sup>133</sup> Assuming typical system parameters for such a project - 25-year life and 1500 kWh - and a 9% cost of capital, the levelized cost of electricity (LCOE) from such systems would be in the range of \$120-\$170/MWh (with the lower-bound for rooftop systems being about \$150/MWh).<sup>134</sup> Note that this LCOE range is competitive with commercial and industrial tariffs throughout all of the countries cited above (Cote d'Ivoire, Ghana, Kenya, Rwanda, and Cameroon), as well as Gabon. It is also well below the IEA's estimated range for diesel-generated electricity of roughly \$255 - \$330/MWh. In the context of Kenya, the payback on such a system would currently be 4-6 years.

**Table 9: Illustrative system economics for a 5 MW ground-mounted PV system in Kenya**

<b>System Size</b>	5 MWp PV
<b>Useful Life</b>	25 years
<b>Annual Yield</b>	1500 kWh/kW
<b>Debt</b>	80% at 7% interest rate
<b>Equity</b>	20% at 17% IRR (WACC is 9%)
<b>Installed Cost</b>	\$1.50/W
<b>LCOE</b>	\$120-\$150/MWh
<b>Simple payback vs. grid-based electricity (\$150/MWh)*</b>	6 years
<b>Simple payback vs. diesel (\$300+/MWh)**</b>	4 years

\* Assumes tariffs escalate at 2.5% per year.

\*\* Assumes diesel price of \$1/liter. Source: CTI/ETA analysis based on proprietary industry sources

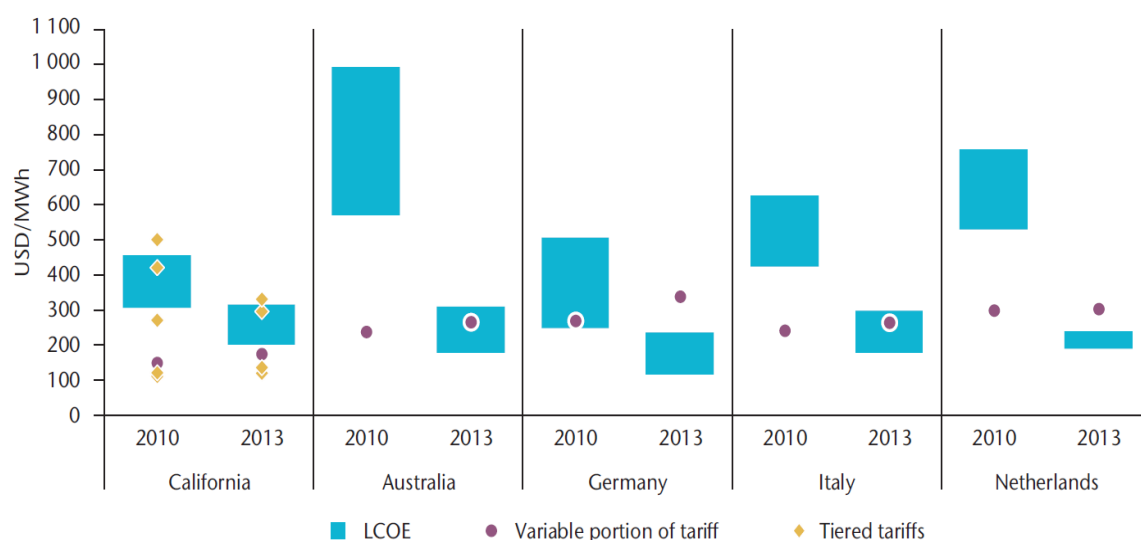
<sup>133</sup> CTI/ETA review of industry sources. For comparison, for 2013, IEA (*Technology Roadmap: Solar Photovoltaic Energy - 2014 Edition*, Table 2) lists commercial PV system prices from \$1.4/W in China to \$4.5/W in the US.

<sup>134</sup> For 2012, the IEA (*Africa Energy Outlook*, Figure 1.25, 58) estimate an average LCOE for large grid-connected solar PV arrays in sub-Saharan Africa of \$175/MWh. Differences between this estimate and those in this paper reflecting continuing reductions in both "hard" (i.e. technology) and "soft" (i.e. installation, permitting) costs in key markets.

Should this LCOE range decline in line with projections for PV systems in the IEA's hi-Ren scenario, it would be \$92-\$130/MWh by 2020 and \$69-\$97/MWh by 2025 (Table 11 above). Recognizing the limitations of LCOE as a metric, this suggests that over the coming decade electricity from distributed PV installations for commercial and industrial customers will be competitive with grid-based electricity throughout much of sub-Saharan Africa, including portions of Southern Africa where tariffs are generally lower than elsewhere in the region. Moreover, with a lower cost of capital (discussed below), the competitiveness of PV will increase substantially.

Note that several countries around the world have already achieved retail “grid parity,” when the LCOE of distributed solar systems declines below the variable (i.e. per kWh) portion of the retail electricity price.<sup>135</sup> Even over the past few years, the speed of this transition has surprised many observers.

**Figure 35: Retail “grid parity” for solar PV in select countries, 2010-2013**



*Note: Household electricity tariffs exclude fixed charges. LCOEs are calculated using average residential system costs (including value-added tax and sales tax in where applicable, and investment tax credit in California); ranges mostly reflect differences in financing costs. The tiered tariffs in California are those of Pacific Gas and Electric. Tiers 3 to 4 or 5 are tariffs paid on monthly consumption when it exceeds given percentages of a set baseline. All costs and prices are in 2012 USD.*

*Source: IEA*

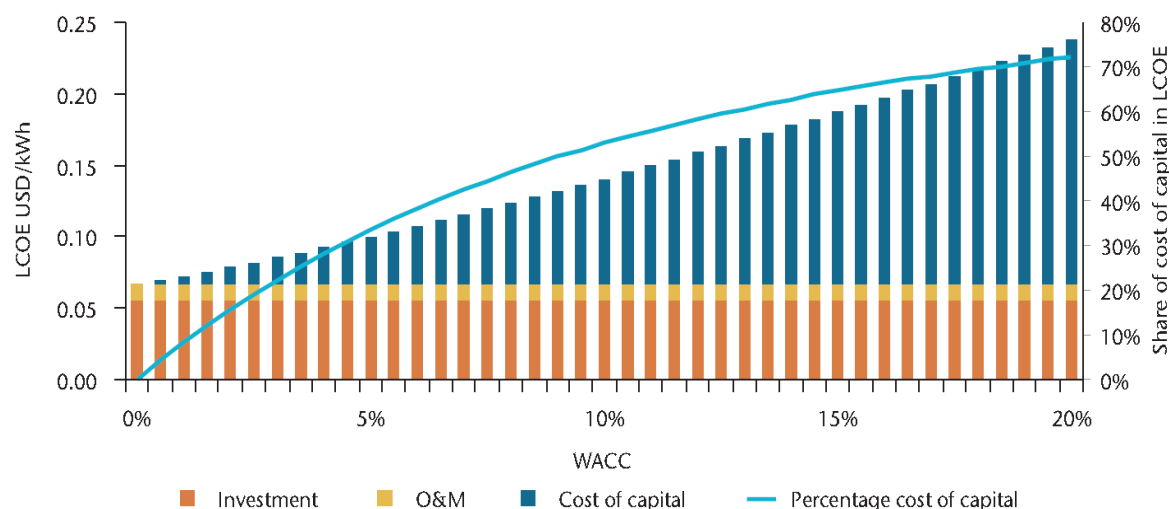
### **Increasing uptake of solar systems via expanded access to financing**

Even where solar PV systems offer attractive return on investment, high upfront costs remain a barrier to adoption. This is particularly true in regions where access to capital is constrained, as is the case throughout much of India and sub-Saharan Africa. Moreover, even where capital is

<sup>135</sup> The IEA ((*Technology Roadmap: Solar Photovoltaic Energy - 2014 Edition*, 15-16) observes that “Grid parity provides an incentive to electricity customers to build a PV system and to generate part of the electricity they consume, and to consume part of the electricity they generate (as more extensively discussed in the System Integration section below). In virtually all power systems, the variable, per-kWh portion of retail prices covers energy costs, most transmission and distribution (T&D) costs, utility or grid operator margins, and various fees and taxes. Grid parity already drives part of the PV deployment in several countries.”

available, high financing costs can erode the competitiveness of solar generation. For example, when a solar PV project's weighted average cost of capital (WACC) exceeds 9%, financing costs comprise over half of total system LCOE. The capital intensity of solar systems makes the cost of capital a critical determinant of overall project economics. For example, for a typical PV project, the IEA calculates that reducing project WACC from 10% to 5% can reduce lower project LCOE from \$150/MWh to nearly \$100/MWh.<sup>136</sup>

**Figure 36: The share of the costs of capital in the LCOE of PV systems**



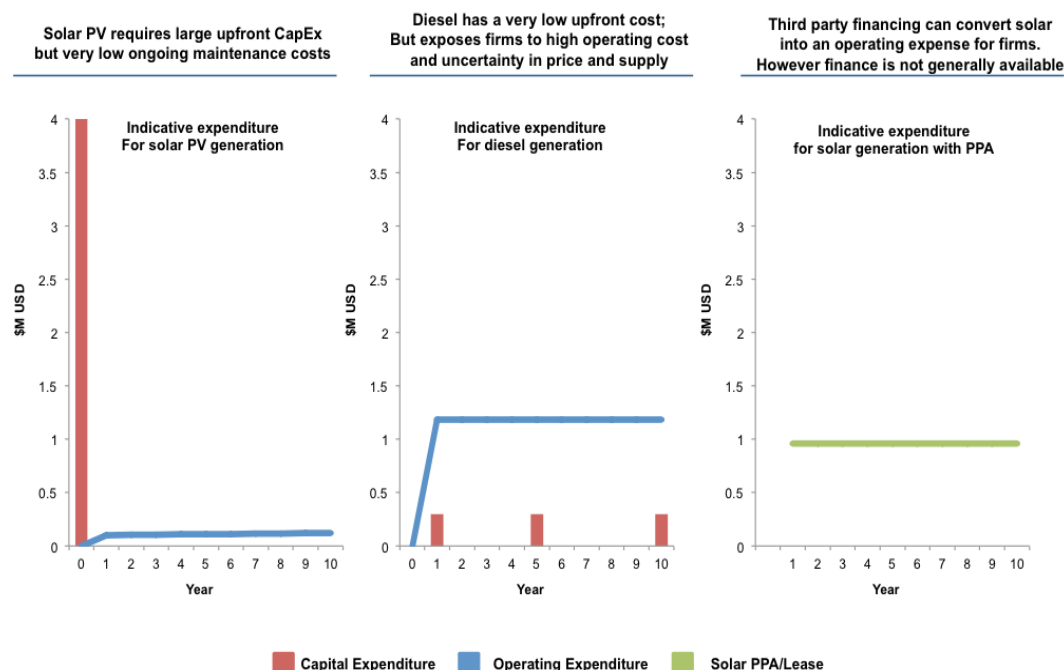
Source: IEA

Notes: This example is based on output of 1 360 kWh/kW/y, investment costs of USD 1 500/W, annual operations and maintenance (O&M) of 1% of investment, project lifetime of 20 years, and residual value of 0.

All of this makes access to financing - at an affordable cost - a critical enabler of PV deployment in developing countries. Analysis above outlined the use of solar leases (i.e. solar power purchase agreements, or solar leases) to expand access to capital for would-be solar customers. By eliminating the need for large initial expenditures to fund installation of a solar system, solar leases can make adoption of solar PV significantly more attractive to potential customers.

<sup>136</sup> IEA (Technology Roadmap: Solar Photovoltaic Energy - 2014 Edition, Figure 12.

Figure 37: Impact of solar lease on customer economics for a 2 MW PV system



Source: CBEG

Just as firms such as Off Grid Electric are using the solar-lease model to extend energy access throughout Africa's rural areas, so other firms are focused on extending solar leases to small and medium-size commercial enterprises throughout Africa. One example of this is CrossBoundary's Distributed Generation Funding Facility, an independent investment platform that will invest in medium-size (.5MW - 5 MW) renewable distributed generation throughout East Africa.<sup>137</sup> The purpose of this entity will be to provide financing solutions to African businesses that could benefit substantially from on-site renewable generation, but that lack the capital to fund such projects. Examples of such businesses include off-grid light manufacturers, mobile phone towers, farms, remote hospitals, eco-lodges and beverage bottlers. Given the impact that solar leases have had on expanding the US solar market, application of solar leases to Africa's commercial sector have the potential to significantly increase deployment of solar PV across the continent.

**Conclusion: There are opportunities for the financial sector to provide the solutions to energy access as finance is often a major obstacle. The costs of renewables options are declining and already becoming competitive against centralized grid options such as coal. Reducing the cost of capital for renewables improves the economics considerably.**

<sup>137</sup> Cross Boundary Energy Group, <http://www.crossboundary.com/#!energy/c1w8x>, accessed 4 Nov 2014.



### ***Potential for local manufacturing, including via new materials and manufacturing methods***

In pursuing new power sources, developing countries often seek more than just electrons. For example, in an effort to create local jobs and promote transfer of new technologies, several developing countries have enacted import tariffs and local content requirements<sup>138</sup> that affect renewable energy products. For example, under India's National Solar Mission program, approved solar PV projects must use locally-manufactured cells and modules.<sup>139</sup> South Africa's Renewable Energy Independent Power Producer Program also imposes a local content requirement that, for the latest round of bidding, stands at 45%.<sup>140</sup> Following a trend in the US and Europe, India also recently considered imposing "anti-dumping" duties of \$0.48-\$0.81/W on silicon-based cells solar cells imported from the US and China; has these duties been adopted, they would have increased the landed cost of imported silicon modules in the Indian market by 80% for US modules and 50% for Chinese modules.<sup>141</sup> Meanwhile, from September 2013 to May 2014 the cost of solar products in Kenya was set to increase owing to a 16% Value-Added Tax on imported goods (in May 2014, Kenya exempted solar products from the tax).

Initiatives such as these underscore how expanding solar penetration in developing countries will likely require greater local manufacturing of solar products. Unsurprisingly, a boom is underway in construction of local silicon factories, with eight new silicon cell and 11 new module factories expected online by 2016 (with another 28 module factories expected by 2018).<sup>142</sup> At least four new module factories are being constructed in sub-Saharan Africa, including small-scale factories with a capacity below 50 MW.

In some cases the economics of producing silicon cells and modules locally - particularly on a small scale - can be economically challenging owing to high capex requirements, instabilities in the supply chain for polysilicon raw material, and the difficulty of customizing silicon modules for small applications. Such difficulties, however, only create opportunities for commercialization of new materials and manufacturing methods. For example, "roll-to-roll" printing methods (using non-silicon materials) offer the potential to greatly simplify solar manufacturing; by reducing the need for process, chemical, and electrical engineers, a simpler manufacturing process creates greater opportunities to use local workers in developing countries. Continuing innovation is lowering the cost of "roll-to-roll" methods to commercially competitive levels; if this occurs, "roll-to-roll" solar factories could lower the required capex for local solar manufacturing while also maximizing the

<sup>138</sup> The World Trade Organization defines a local-content requirement as a "requirement that the investor purchase a certain amount of local materials for incorporation in the investor's product." Local-content measure; online: [http://www.wto.org/english/thewto\\_e/glossary\\_e/glossary\\_e.htm](http://www.wto.org/english/thewto_e/glossary_e/glossary_e.htm) (accessed 3 Nov 2014)

<sup>139</sup> Olivier Johnson, "Exploring the Effectiveness of Local Content Requirements in Promoting Solar PV Manufacturing in India," German Development Institute Discussion Paper, Nov 2013.

<sup>140</sup> Ben Kane and MJ Shiao, "How Real Is the South African PV Market," GreenTech Media, 14 Aug 2013, <http://www.greentechmedia.com/articles/read/How-Real-Is-The-South-African-PV-Market>

<sup>141</sup> Trefis Team, "First Solar Could Benefit if India Imposes Duties on Solar Cell Imports," Forbes, 11 Jun 2014, <http://www.forbes.com/sites/greatspeculations/2014/06/11/first-solar-could-benefit-if-india-imposes-duties-on-cell-imports/>

<sup>142</sup> Navigant Consulting.

potential for local job-creation. Advances such as these will be essential to further integrating renewable energy technologies into the energy mixes of developing countries.

**Conclusion: there will be opportunities for developing countries to participate in the development of clean energy industries, providing jobs and revenues based on clean energy.**

### ***Hybrid PV/diesel systems for enterprises***

Many of the smaller start-up enterprises that have always been the main stay of any vibrant economy, particularly in terms of employment creation, require power in the kilowatt range rather than the megawatt. They are ideally suited for smaller hybrid power solutions. Right now they are dependent on diesel mostly and central power systems that frequently prove to be unstable and quite variable in their performance. Hence a local solution is already proposed by many.

The key calculation is indeed the cost and capital expenditures of installing a hybrid system verses diesel right now and longer term verses a central grid. Assuming that grid is stable. These distributed enterprise grids can be linked locally to other enterprises and indeed local homes in a more controlled fashion that always the better management of payment and proper use.

Figure 32 above illustrates the benefits of on-site generation in the form of significantly reduced electricity losses. There is also a cost to on-site generation, however, in the form of the expense paid to produce electricity from diesel generators. For sub-Saharan Africa, the IEA estimates costs for diesel-generated electricity of roughly \$255/MWh (assuming a diesel price of \$0.75/liter) to \$330/MWh (assuming a diesel price of \$1/liter).<sup>143</sup> Moreover, Appendix B suggests that in certain parts of Africa the costs of diesel generation can reach \$400-\$500/MWh. The analysis above has already suggested the cost of electricity from new solar PV installations (including rooftop installations) to be below these levels. Maximizing reliability, however, requires integrating solar PV into a hybrid system capable of supplying power even at night or during periods when solar irradiance is low.

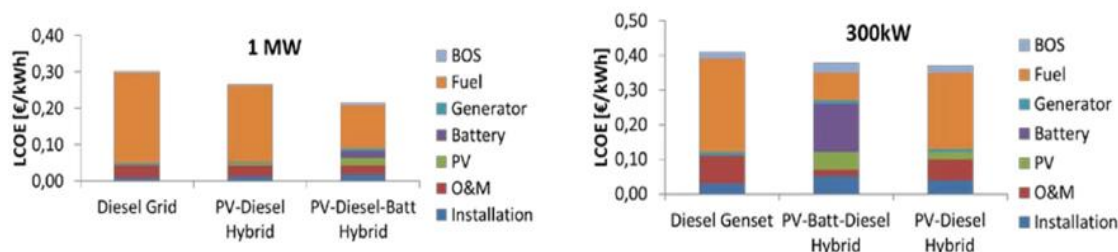
### ***Declining battery costs continuing to improve economics of hybrid systems***

Including battery storage in hybrid PV/diesel systems enables a greater portion of load to be met through solar power, reducing reliance on costly diesel generation. Current battery prices, however, often constrain the amount of storage capacity that it is economical for hybrid diesel/PV systems to employ. For example, in the case of a 300 kW system, each MWh charged via battery typically adds \$200/MWh or more in cost - making battery costs 30% or more of the LCOE of such a system. As a result, the LCOE of PV/diesel-battery hybrid systems ranges from roughly \$270/MWh (for a 1 MW system) to over \$450/MWh (for a 300 kW system).<sup>144</sup>

<sup>143</sup> IEA, *Africa Energy Outlook*, Figure 1.25.

<sup>144</sup> Georg Dielmann, Martin Rothert, and Volker Wachenfeld, "OPTIMIZING PV-DIESEL-BATTERY HYBRID SYSTEMS

**Figure 38: Typical LCOE of a 1 MW (left-hand side) and 300 kW (right-hand side) PV/diesel/battery hybrid system**



Source: Dielmann, Rothert, and Wachenfeld

Though generally still less expensive than diesel generation (assuming a diesel price of at least \$1/liter), the difference has to date been too small to motivate widespread adoption. Projected declines in battery costs, however, are set to make the economics of PV/diesel-battery hybrid systems more attractive. *The economics of PV/diesel hybrid systems, however, are continuing to improve as a result of declining technology costs for PV modules, inverters, and batteries.* Discussion above noted installed solar PV costs in East Africa falling to \$1.80-\$2.00/W for rooftop systems and as low as \$1.50/W for larger ground-mounted systems (versus \$2.80/W, for an admittedly small system, in the sample PV/diesel system analyzed in Figure 16 earlier). *Equally critical, however, is the projected reduction in battery costs for grid-scale energy storage.* The lead-acid batteries in the system above, for example, have a cost of \$255/kWh (i.e. \$255 per kW per hour of operation). With respect to grid-scale energy storage, many alternative battery chemistries have efficiencies, cycle durabilities, and other performance characteristics that are superior to lead-acid. Adoption of these alternative batteries, however, has been slow due to high costs.

Growth of the worldwide battery market, however, is enabling significant reductions in the cost of batteries. For example, as of five years ago lithium-ion batteries were selling for a price of \$1200-\$1500/kWh (this metric is per kW per hour of operation). Currently, however, Tesla Motors is sourcing lithium-ion batteries from Panasonic at a price of \$180/kWh, which is regarded as the "established low-cost price for high-quality batteries."<sup>145</sup> Moreover, the cost of processed chemical materials going into these batteries is only \$69/kWh. Since the cost of a battery is only ~10-20% higher than the cost of materials, UBS analysts observe that "a potential long-term competitive price for Lithium-Ion batteries could approach ~\$100 per kWh."<sup>146</sup> Note that a battery cost of \$100/kWh would be 60% lower than the \$255/kWh cost in the sample analyses above.

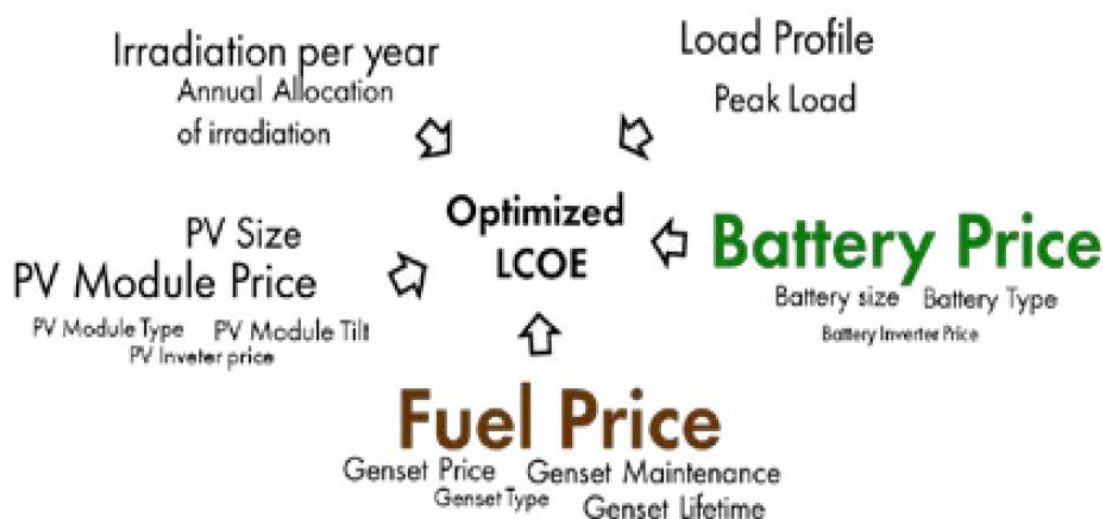
TO ACHIEVE LOWEST POSSIBLE LCOE," 28th European Photovoltaic Solar Energy Conference and Exhibition, Sep 2013. Very small systems, on the order of 10 kW, can have costs as high as \$600/MWh, with battery and PV costs accounting for a greater percentage of overall LCOE (and fuel a correspondingly smaller percentage), as at this level of load there is less need to rely on back-up diesel generation.

<sup>145</sup> SFC Consulting

<sup>146</sup> UBS, "The Storage Opportunity (Including Conference Call Transcript)"

Given that batteries can account for 30-35% of the LCOE of a 300 kW PV/diesel/battery hybrid system<sup>147</sup>, battery costs of \$100/kWh could reduce overall system LCOE by 20%. The result will be shorter payback periods, competitiveness against a lower range of diesel prices, and adoption in a broader variety of geographies and applications.

Figure 39: Impact of various inputs on the LCOE of mini-grids



Note: Size of input corresponds to its relative impact.  
Source: Dielmann, Rothert, and Wachenfeld

### Continued technological innovation for hybrid systems

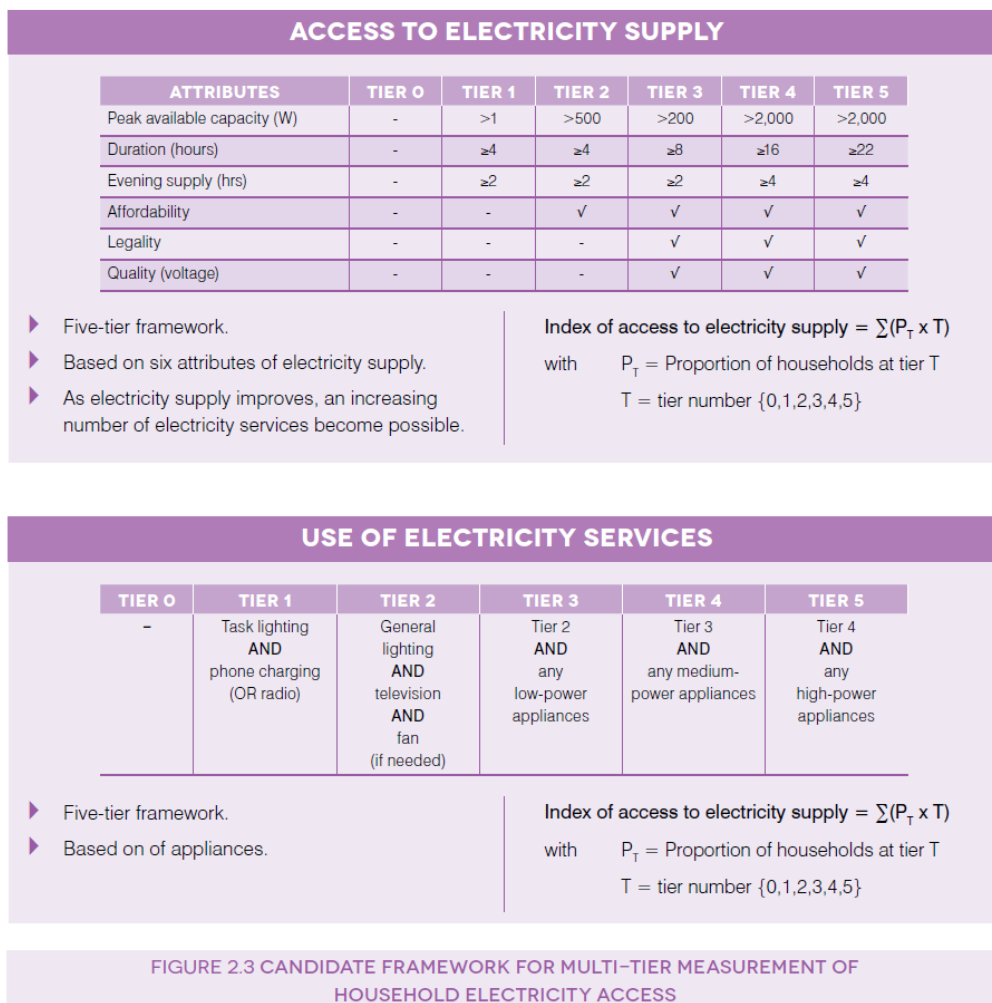
Moreover, continuing technological innovation is expanding potential deployment of hybrid systems. California-based start-up Automatiks, for example, manufactures stationary hybrid systems that combine a solar PV array, a battery, a diesel generator, and (where available) grid supply.<sup>148</sup> These units come as a single or double container that can replace a 20-250 kVA diesel generator. Importantly, they also can be flexibly sized and configured to meet varied customer power requirements. Applications range from totally off-grid (e.g. remote telecom towers) to supplementing or replacing intermittent grid and diesel generation. The modularity of such systems has the potential to significantly reduce balance of system costs, which equal 15-20% of the cost of a diesel/PV hybrid system.

**Conclusion: The development of hybrid systems where the share of solar PV increases as the cost of batteries decline is one of the most exciting opportunities for bringing a reliable low cost solution to Africa and India.**

<sup>147</sup> Georg Dielmann, Martin Rothert, and Volker Wachenfeld, "OPTIMIZING PV-DIESEL-BATTERY HYBRID SYSTEMS TO ACHIEVE LOWEST POSSIBLE LCOE."

<sup>148</sup> Automatiks, "Products," Automatiks.com, accessed 4 Nov 2014

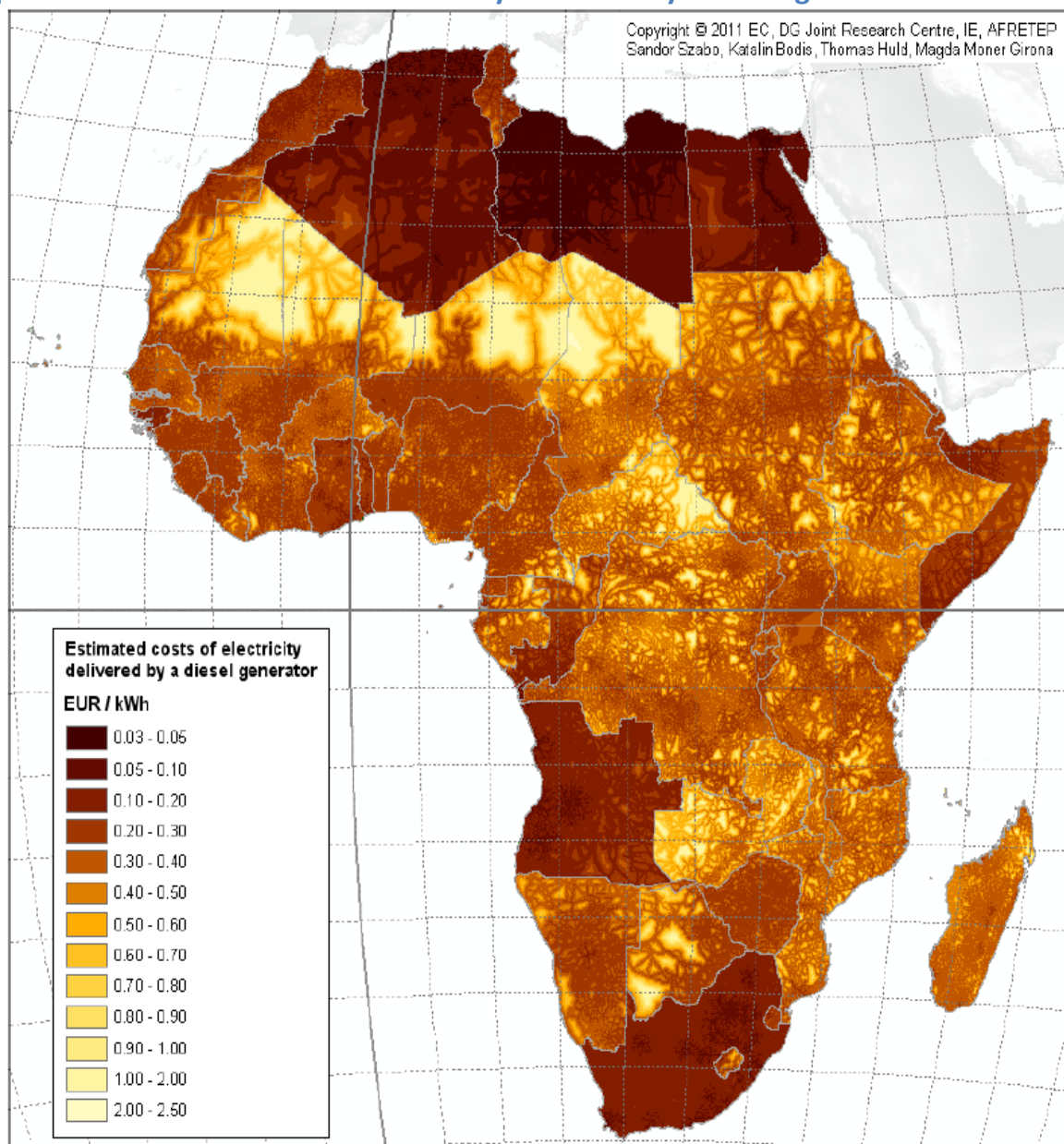
## Appendix A: SE4ALL Criteria for Access to Electricity



SOURCE: AUTHORS

TRACKING ACCESS TO ELECTRICITY	GLOBAL TRACKING	NO ACCESS	NO ACCESS	ADVANCED ACCESS			
		NO ELECTRICITY	SOLAR LANTERN OR RECHARGEABLE BATTERY LANTERN	HOME SYSTEM OR GRID CONNECTION			
	COUNTRY-LEVEL TRACKING	TIER-0	TIER-1	TIER-2	TIER-3	TIER-4	TIER-5

## Appendix B: Estimated costs of electricity delivered by a diesel generator






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