
Sustainable Energy

Options for Africa

Robert Stoner
Associate Director
MIT Energy Initiative



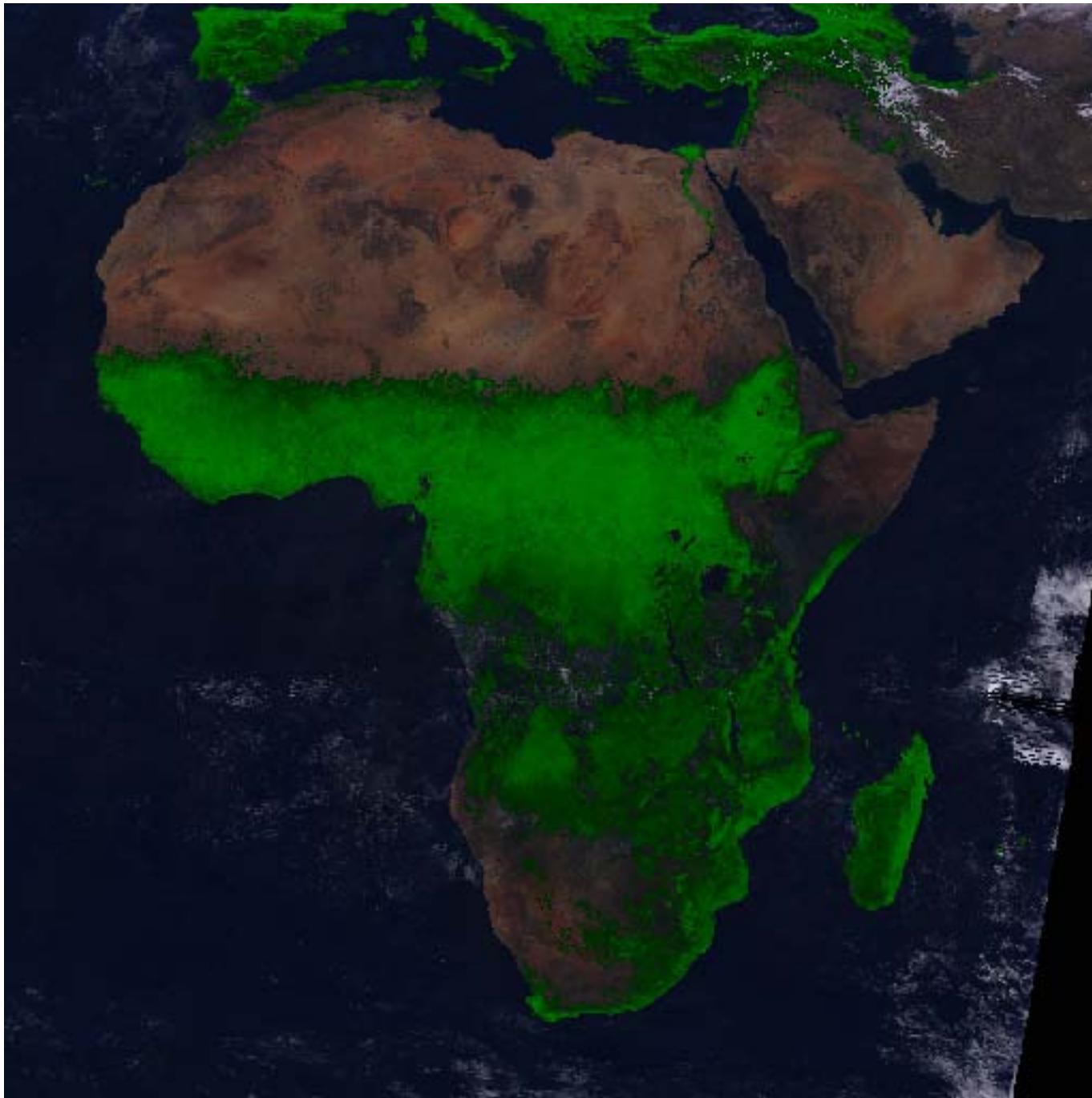
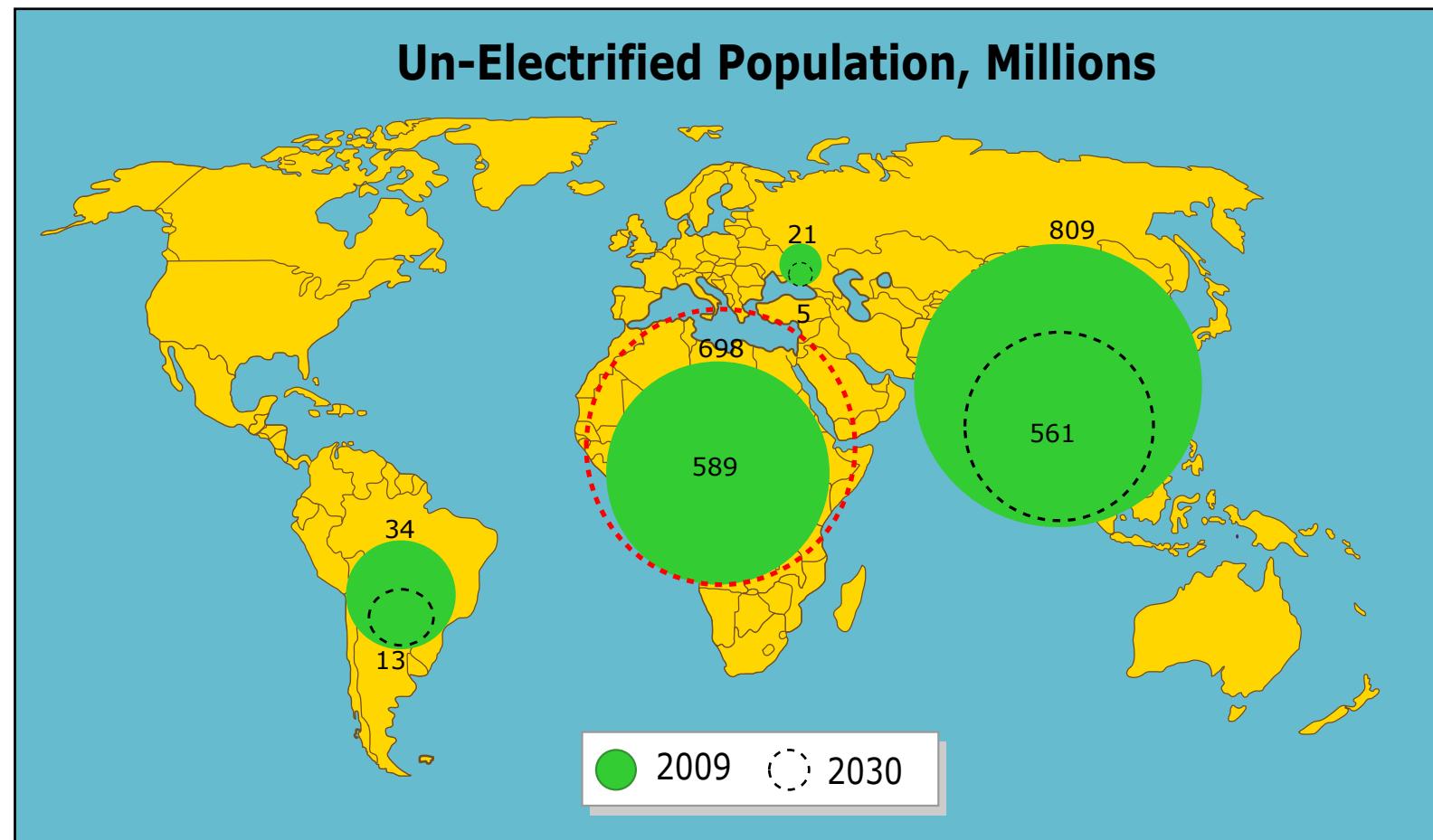


Photo by NASA Visible Earth, Goddard Space, Flight Center Scientific Visualization Studio.

Rwinkwavu, Rwanda



Unique Africa



By 2030 roughly 1.3 billion people will remain un-electrified. With Africa's un-electrified projected to grow to 700 million, gains made in other regions will be largely negated.

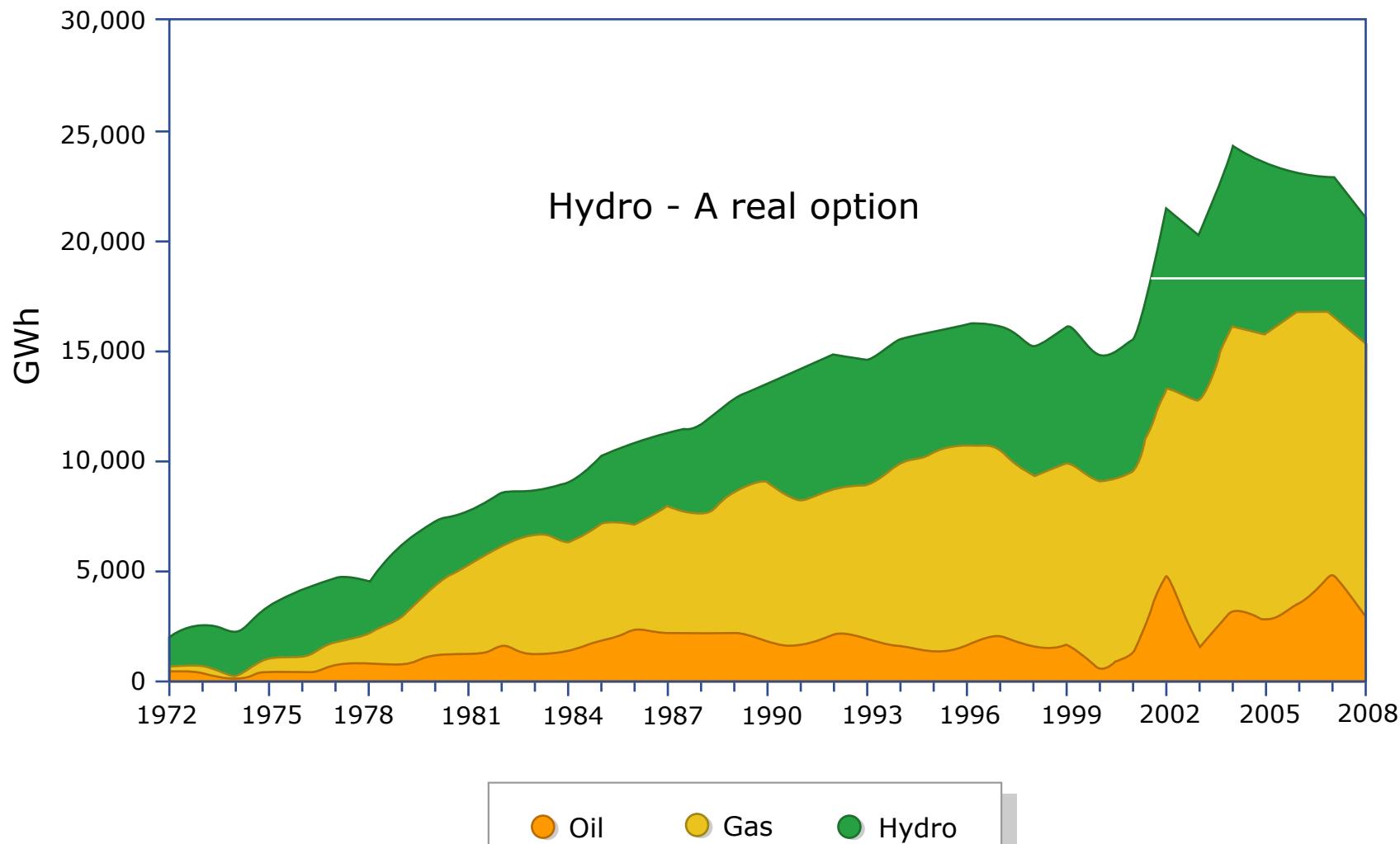
Four “Typical” Countries

	<i>South Africa</i>	<i>Egypt</i>	<i>Nigeria</i>	<i>Kenya</i>
Population (million)	49.1	80.5	152	40
Pop. Growth Rate (%)	-0.05%	2.00%	2.00%	2.60%
Urban Pop. (%)	61%	43%	48%	22%
Urban Pop. Growth Rate	1.40%	1.80%	3.80%	4.00%
GDP (Exchange Rate \$Billion)	\$287.2	\$188.0	\$173.0	\$32.7
GDP per capita (\$)	\$5,849	\$2,335	\$1,138	\$818
Electricity per capita (kWh)	4,894	1,471	126.38	122
Urban Growth per year (millions)	0.42	0.62	2.8	0.35
Rural Growth per year (millions)	-0.44	0.99	0.27	0.69
% Change to Urban Annually	1.76%	-0.45%	1.65%	-0.84%

(Source: CIA Factbook)

The lack of rural electrification will be with us for a long time.

Electricity Generation by Fuel in Nigeria

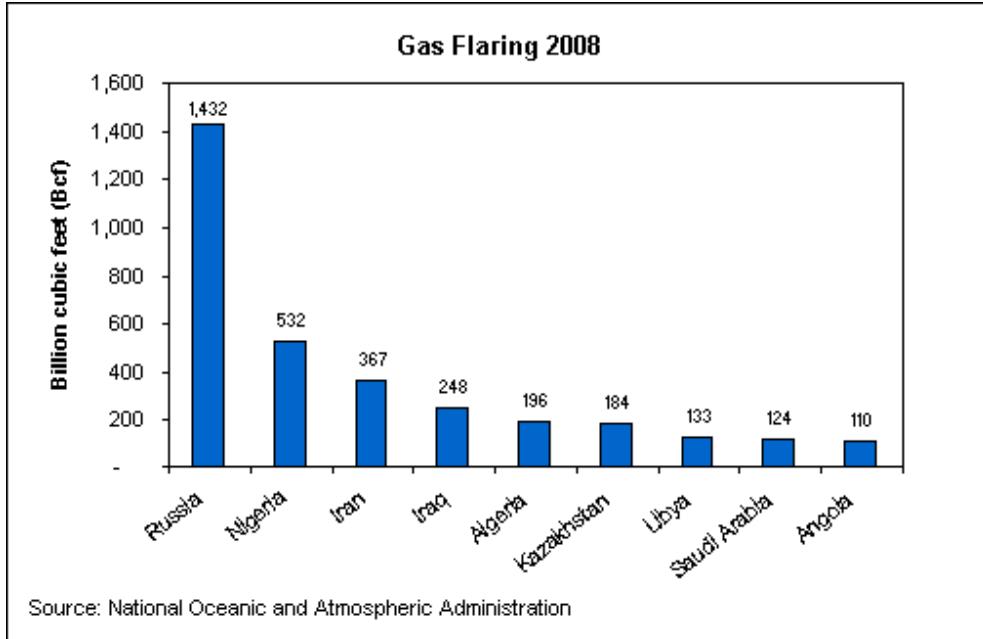


Energy in OPC's

	Total Population, 2006 (million)	Number of people without electricity access (million)	(%)	Number of people relying on fuelwood and charcoal for cooking (million)	(%)
Angola	16.6	14.6	88	15.7	95
Cameroon	18.2	14.2	78	14.2	78
Chad	10.5	10.1	97	10.2	97
Congo	3.7	2.9	78	2.9	80
Côte d'Ivoire	18.9	11.6	61	14.7	78
Equatorial Guinea	0.5	0.4	73	0.3	59
Gabon	1.3	0.9	70	0.4	33
Mozambique	21	18.6	89	16.9	80
Nigeria	144.7	76.6	53	93.8	65
Sudan	37.7	26.9	71	735.2	93
Total	273.1	176.9	65	204	75

Image by MIT OpenCourseWare. Source: IEA World Energy Outlook 2008.

Gas Flaring in Nigeria



2nd next to Russia
25% of gross production

Graph from [Country Analysis Brief: Nigeria](#).
U.S. Energy Information Administration, July 2010.

How much e is that?

532 bcf \approx 156B kWh
@50% \approx 80B kWh
(Consumption \approx 20B kWh)

Photo of [gas flares in Nigeria](#) removed
due to copyright restrictions.

Gas – an option for Nigeria

Text removed due to copyright restrictions. Please see Layne, Rachel. "GE Gas Turbines to be Added to Nigerian Omotosho Plant." Bloomberg L. P., November 22, 2010.

Create Options for Neighbors

Map of Africa showing locations of existing, planned, or under construction oil and pipelines and other energy infrastructure has been removed due to copyright restrictions.
Please see Fig. 15.5 in [World Energy Outlook 2008](#). OECD/IEA, 2008.

Source: IEA World
Energy Outlook 2008
Compiled from PFC
Energy and Petroleum
Economist.



LPG

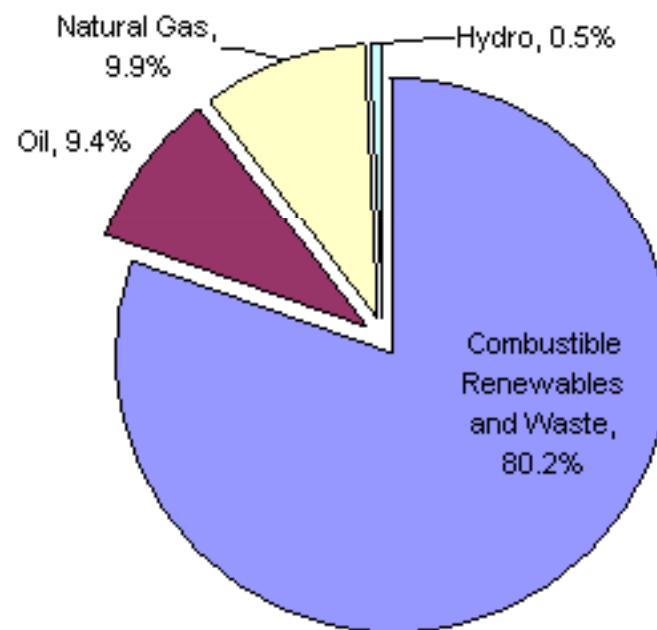
Liquified Petroleum Gas

12% of households
\$50-\$100 system cost

Competes with wood.

Nigerian Deforestation

Total Energy Consumption in Nigeria, by Type (2007)



Forest cover loss >40%
(since 1990).

Loss is >3.3% per year.

75% of timber is imports.

Source: International Energy Agency (IEA)



Powering Nigeria – a little

150M people

5 people/HH

50% without electricity

...so we need 15M connections

Capital for T&D @ \$1,000/HH is \$15B

Capital for Generation @ 1kWh/HH/day

15M kWh/day + 5M kWh/day (losses)

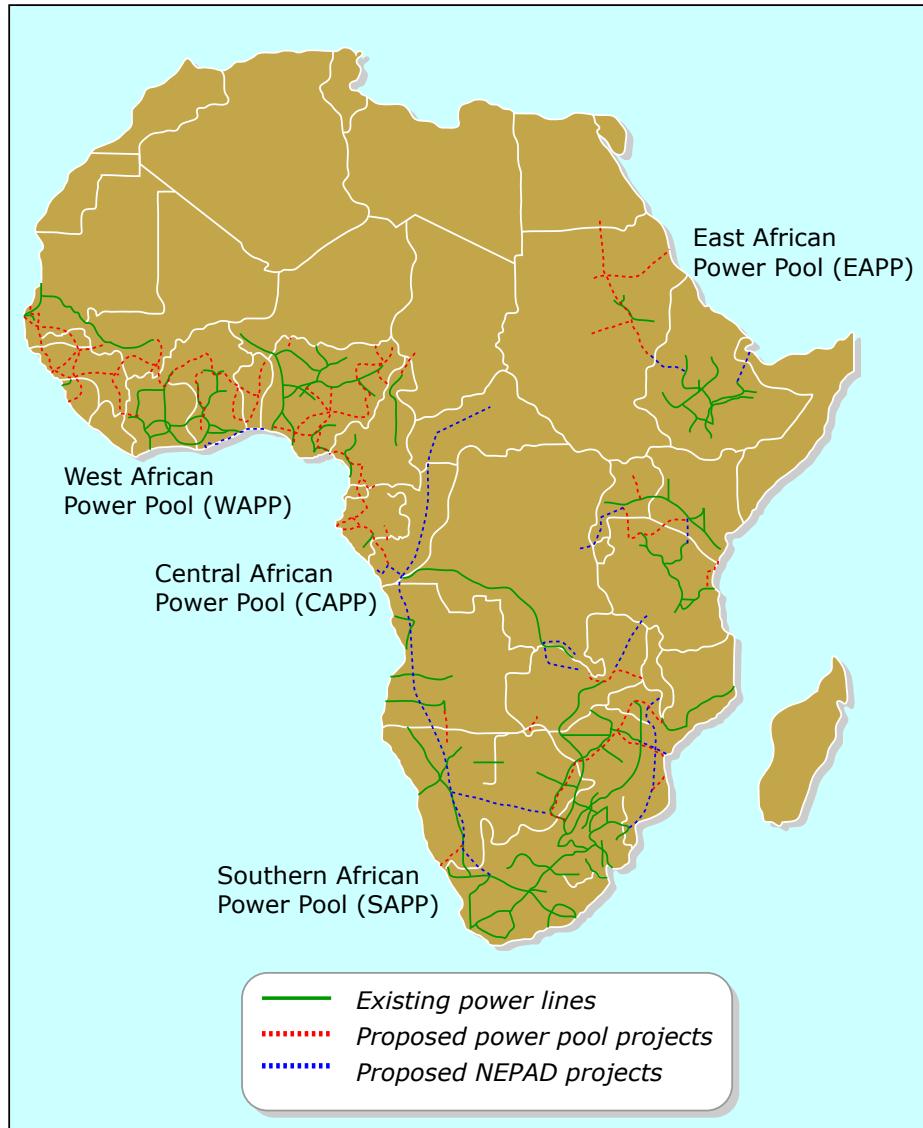
= 20M kWh/day

Assume 4 hours per day level load...5M kW or 5 GW.

So, buy 10GW nameplate capacity @ \$1,000/kw (gas) for \$10B.

Total capital is \$15B+\$10B=\$25B. (equal to Federal Budget)

African Power Pools



- Economies of scale
- Greater reliability
- Larger loads
- Options for resource poor

Image by MIT OpenCourseWare. Adapted from [World Energy Outlook 2008](#). Source: NEPAD data.

The Solar Option

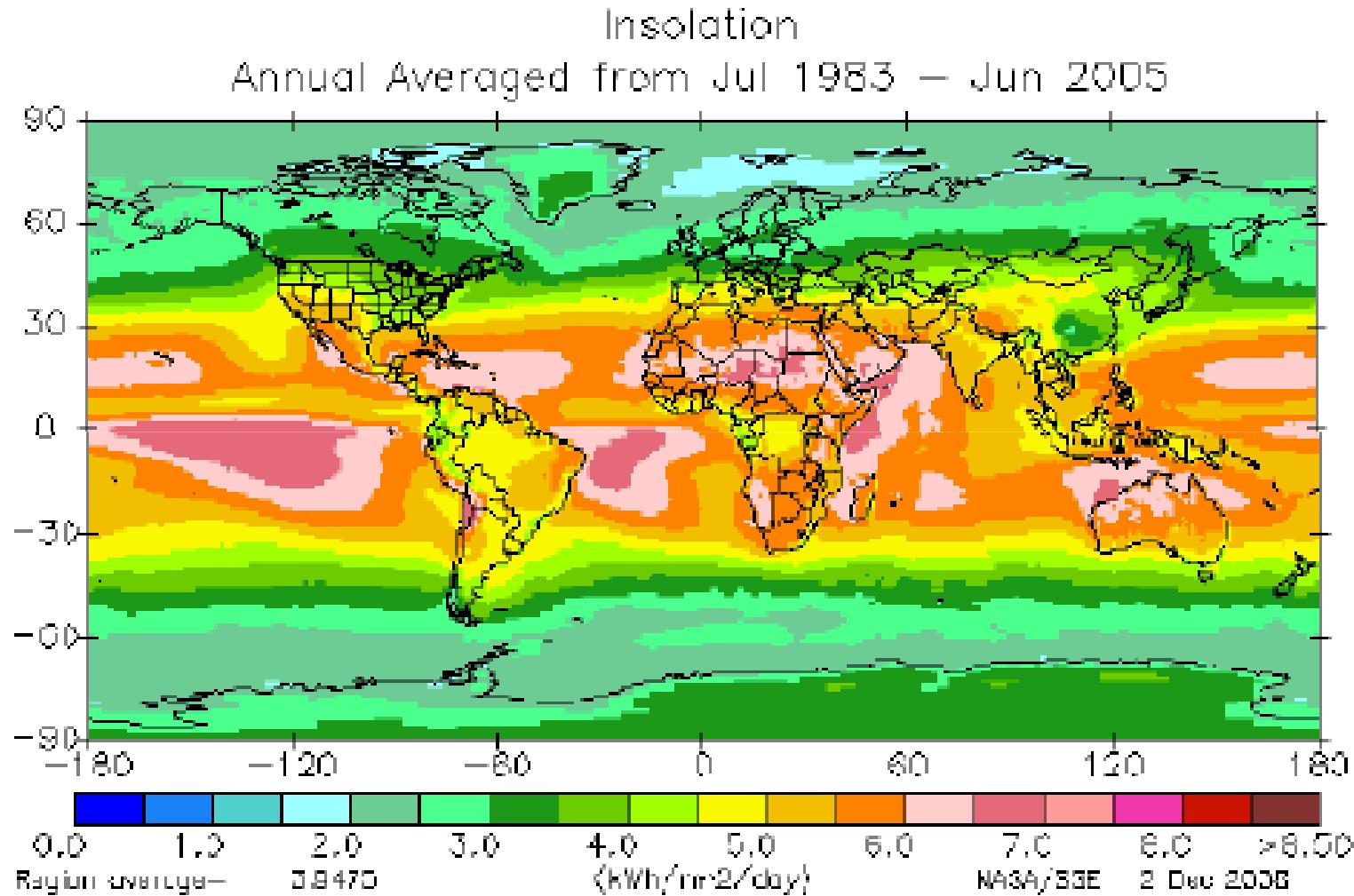


Image by [NASA Atmospheric Science Data Center, Surface Meteorology and Solar Energy](#).

Global Horizontal Incidence

Please see "[Africa Global Horizontal Solar Radiation - Annual.](#)" NREL, November 2005.

Solar Home Systems (SHS)

Component-wise
\$500-\$1000

Images removed due to copyright restrictions.

System in a Box
\$200-\$1500

Solar Lanterns

Image removed due to copyright restrictions. Please see "[Solar Lanterns Test: Shades of Light](#)." GTZ, May 2009.

Egypt and North Africa

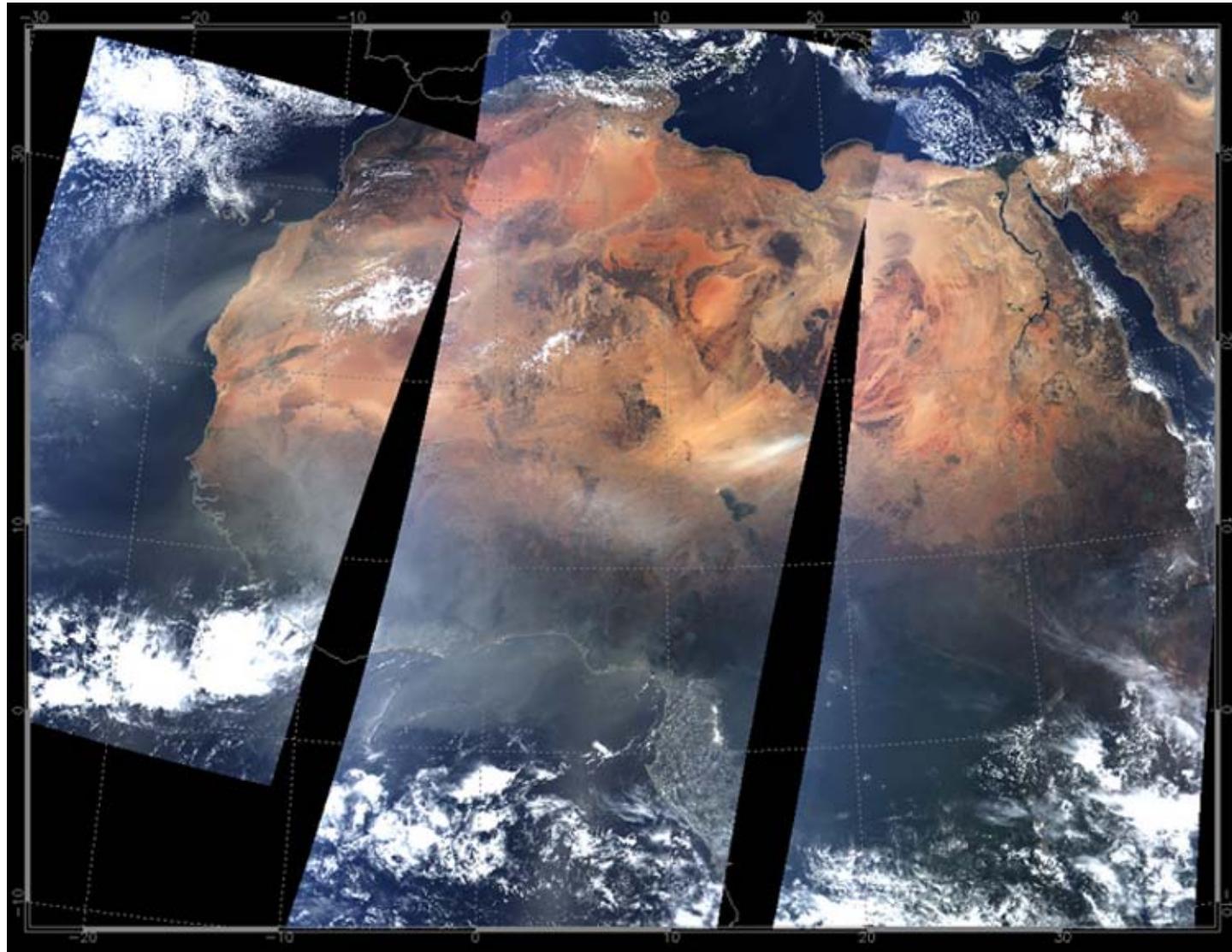


Photo by Liam Gumley, University of Wisconsin - CIMMS,
NASA Visible Earth, Goddard Space Flight Center.

Direct Normal Incidence

Please see "[Africa Direct Normal Solar Radiation - Annual.](#)" NREL, November 2005.

Concentrated Solar



Photo by [Idrose](#) on Flickr.

Trough



Tower



Photo by [afloresm](#) on Flickr.

\$3-5/kW

Desertec



Courtesy of Dii GmbH. Used with permission.

Vision: Coastal CSP Plants provide electric power to Europe and North Africa + Desalination. (approx. 600kmx600km completely filled.)

(Source: David MacKay, *Sustainable Energy Without the Hot Air*.)

Country	Economic potential (TWh/y)	Coastal potential (TWh/y)
Algeria	169 000	60
Libya	140 000	500
Saudi Arabia	125 000	2 000
Egypt	74 000	500
Iraq	29 000	60
Morocco	20 000	300
Oman	19 000	500
Syria	10 000	0
Tunisia	9 200	350
Jordan	6 400	0
Yemen	5 100	390
Israel	3 100	1
UAE	2 000	540
Kuwait	1 500	130
Spain	1 300	70
Qatar	800	320
Portugal	140	7
Turkey	130	12
Total	620 000 (70 000 GW)	6 000 (650 GW)

*World Energy Consumption 132,000 TWh/yr

Desertec

e.g. Tunisia:

**GDP Impact @ \$0.05/kWh
\$17.5B/year in sales to europe.**

(BUT Levelized Cost = \$0.20/kWh !!)

Whatever...what does it cost?

**To generate 350,000 GWh/yr
Required CSP Capacity 100GW**

**Cost of 100GW CSP @ \$5,000/kW
\$500B**

The Hydro Option

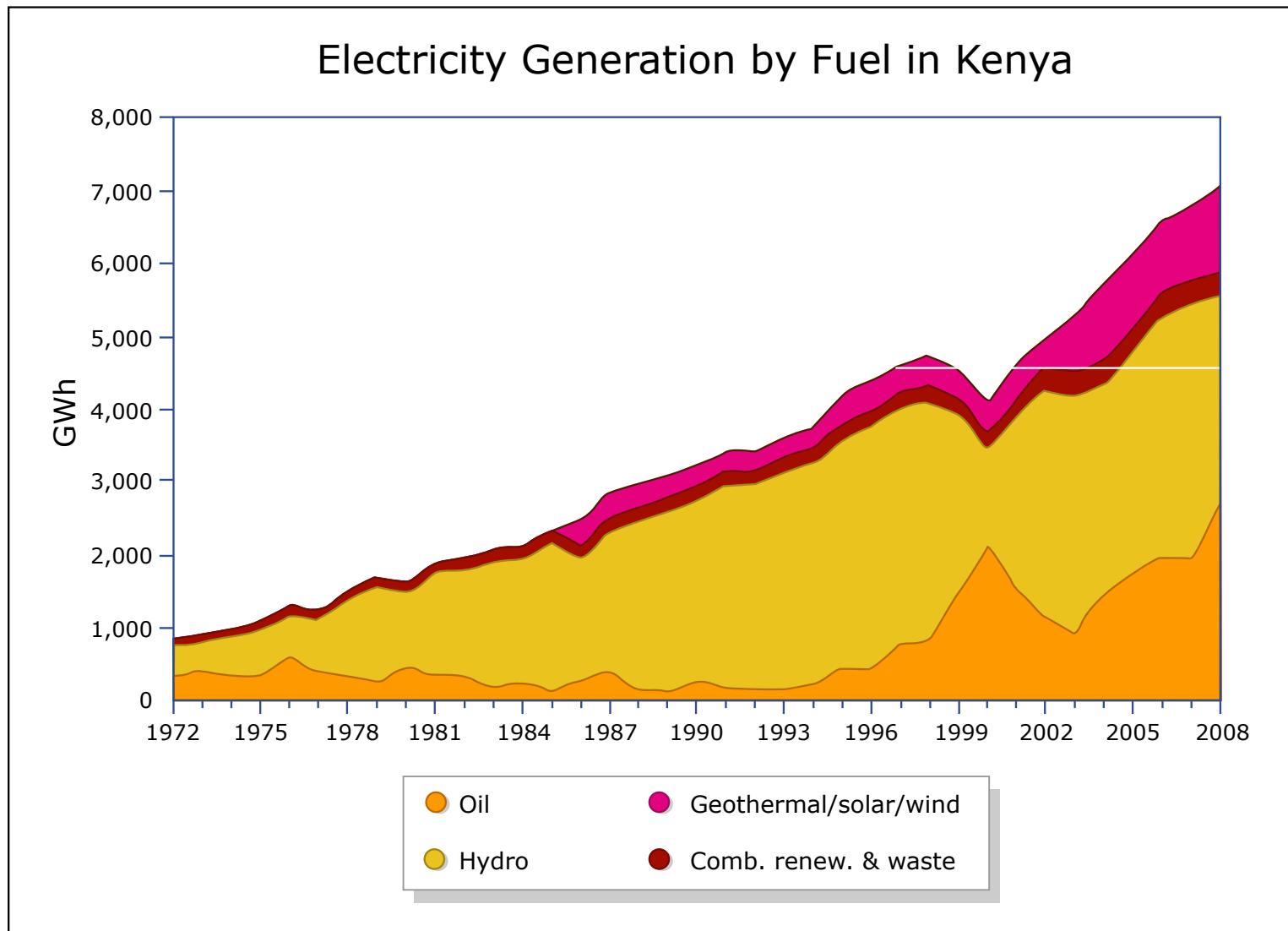


Image by MIT OpenCourseWare. Source: IEA.

Deforestation

Please see maps in Fig. 1 and Site 9: Eldama Ravine Constituency, Koibatak District in Akotsi, Erick F. N., Michael Gachanja, and Jacob K. Ndirangu. "[Changes in Forest Cover in Kenya's Five 'Water Towers,' 2003-2005.](#)" DRSRS/KFWG, November 2006.











The Geothermal Option

Rift Valley

Potential 4-8GW

Africa Rift Valley Geothermal Development Facility (ARGeo) - \$18M

Kenya, Ethiopia, Djibouti, Eritrea, Uganda, Tanzania

Olkaria Complex (I-IV)

- 175MWe installed (200MW nationally)
- 800MWe potential (2-4GW nationally)
- Objective is 1200MW by 2015
- 280MW in Olkaria I and IV just started (2013)
 - \$1.314B (i.e., \$4,700/kW) *all in.*



Photo of the geothermal power plant at Olkaria removed due to copyright restrictions.
Image by [NASA/JPL/NIMA](#).

Nuclear Kenya

Photo of a nuclear power plant near the ocean has been removed due to copyright restrictions.

African Power Pools - Again

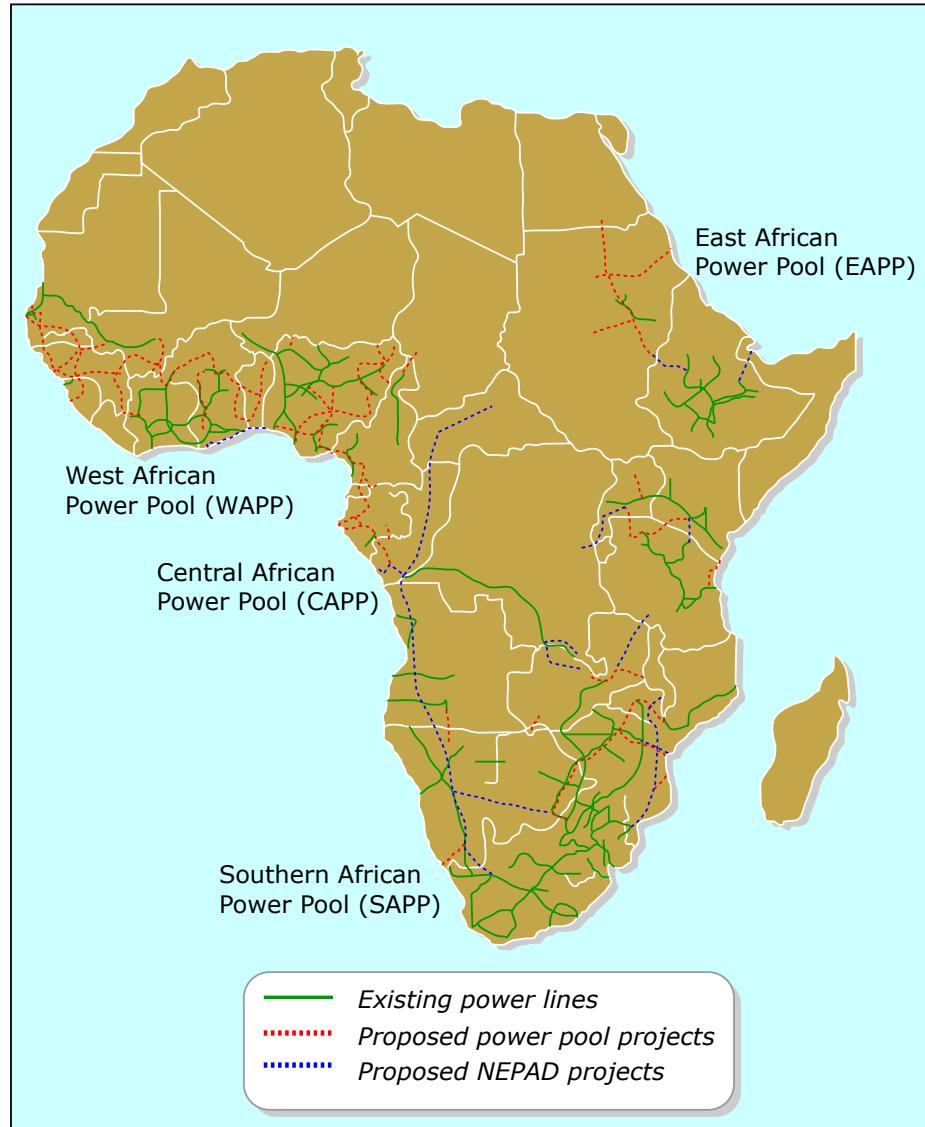


Image by MIT OpenCourseWare. Adapted from [World Energy Outlook 2008](#). Source: NEPAD data.

South Africa



Image by Jacques Descloitres, MODIS Land Group,
NASA Visible Earth, Goddard Space Flight Center.

Post Apartheid Electrification

Photo of South Africa showing power lines overhead in filthy urban area has been removed due to copyright restrictions.

South African Innovations

Innovations:

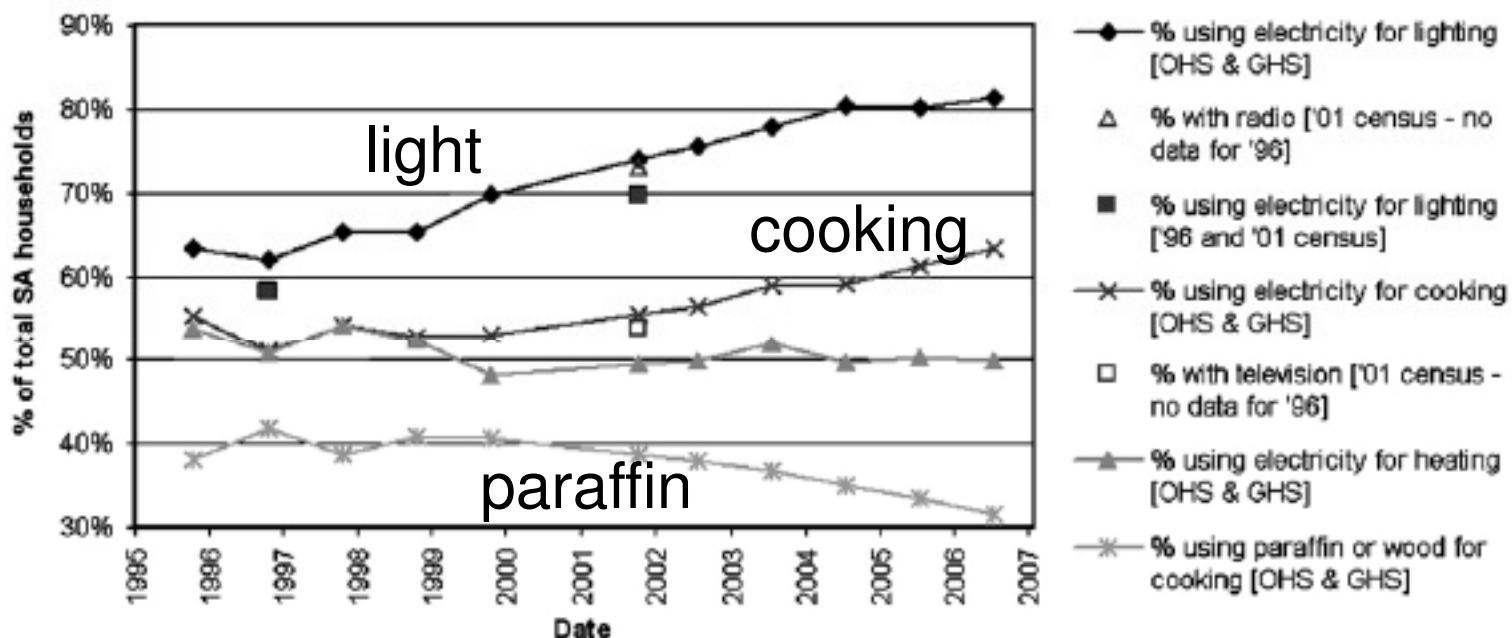
- Elimination of 3-phase standard approach.
- Adoption of SWER and other cost reduction strategies.
- Readiboards.
- Prepaid meters.
- Blanket electrification.
- Revised standards for small consumers – enabled use of cheaper cabling.

85% and Counting

Map removed due to copyright restrictions. Please see Fig. 2 in "[Community Electricity in Rural South Africa: Renewable Mini-Grid Assessment.](#)" ScottishPower/G7, 2004.

Electrification Impact

B. Bekker et al. / Energy Policy 36 (2008) 3115–3127



Courtesy of Elsevier, Inc., <http://www.sciencedirect.com>. Used with permission.

Adoption for cooking significantly lags lighting
displacing paraffin and wood.

Coal Dependence

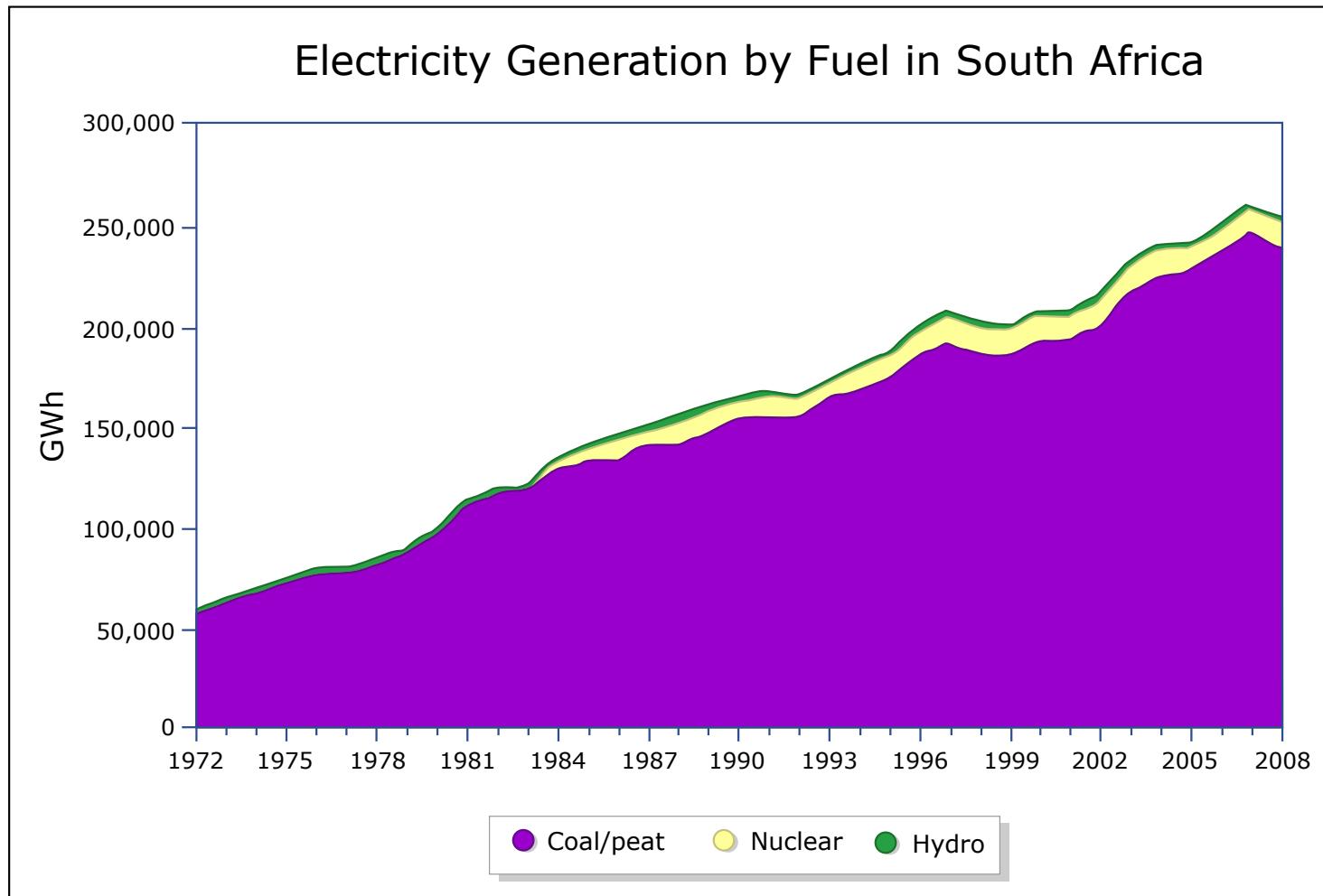


Image by MIT OpenCourseWare. Source: IEA.

Medupi – Clean Coal!



\$4.5B
880 ha
6x800MW

April 2010.

Photography by Anthony Allen, www.aerialphoto.co.za. Used with permission.

South Africa's REFIT

Parameter	Units	Wind	Small Hydro	Landfill Gas Methane	Concentrated Solar Plant (CSP), Parabolic Trough with Storage (6 hrs per day)
Capital cost: engineering procurement & construction (EPC)	\$/kW	2000	2600	2400	4700
Land cost		5%	2%	2%	2%
Allowance for funds under construction (AFUC)		4.4%	10.6%	4.4%	4.4%
Tx/Dx integration cost		3%	3%	3%	3%
Storage (CSP)		-	-	-	8%
Total investment cost	\$/kW	2255	3020	2631	5545
Fixed O&M	2009\$/kW/Yr	24	39	116	66
Variable O&M	2009\$/kWh	0	0	0	0
Economic life	Years	20	20	20	20
WACC		12%	12%	12%	12%
Plant lead time	Years	2	3	2	2
Fuel type		Renewable	Renewable	Renewable	Renewable
Fuel cost	\$/10^6BTU	0	-	1.5	0
Fuel cost	\$/kWh	-	0.00106	-	
Heat rate	BTU/kWh	-	-	13500	-
Assumed load factor		27%	50%	80%	40%
Levelised cost of electricity production	\$/kWh	0.1247	0.0940	0.0896	0.2092
Exchange rate R/\$	ZAR/\$	10	10	10	10
Levelised cost of electricity production	R/kWh	1.247	0.940	0.896	2.092

Image by MIT OpenCourseWare. Adapted from National Energy Regulator of South Africa. Table shows the Renewable Energy Feed-in Tariff (REFIT) schedule.

Upington Solar Park

Please see "[Africa Direct Normal Solar Radiation - Annual.](#)" NREL, November 2005.

Take Aways

- Africa is a big place – the options are as varied as the terrain.
- Energy and the sustainability of the population are inseparable.
- The industrialization track (mainly urban), and quality of life track (mainly rural) must both be pursued.
- Technical innovation will be crucial to meet scale and cost requirements of the market.

MIT OpenCourseWare
<http://ocw.mit.edu>

22.081J / 2.650J / 10.291J / 1.818J / 2.65J / 10.391J / 11.371J / 22.811J / ESD.166J

Introduction to Sustainable Energy

Fall 2010

For information about citing these materials or our Terms of Use, visit: <http://ocw.mit.edu/terms>.