NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

Technical Potential of Solar Energy to Address Energy Poverty and Avoid GHG Emissions in Africa

INTRODUCTION

Approximately 1.6 billion people worldwide do not have access to electricity, and roughly 2.4 billion people rely on traditional biomass fuels to meet their heating and cooking needs (IEA 2002). Lack of access to and use of energy—or energy poverty—has been recognized as a barrier to reaching the Millennium Development Goals (MDGs) and other targeted efforts to improve health and quality of life (IEA 2002). Reducing reliance on traditional biomass can substantially reduce indoor air pollution-related morbidity and mortality; increasing access to lighting and refrigeration can improve educational and economic opportunities. Though targeted electrification efforts have had success within Latin America and East Asia (reaching electrification rates above 85%), sub-Saharan Africa has maintained electrification rates below 25% (IEA 2004).

This analysis explores the technical potential of photovoltaics (PV) or concentrating solar power (CSP) to address energy poverty in Africa through a geographic information system (GIS) screening of solar resource data developed by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). This analysis does not aim to address the economic and social factors that will influence realization of PV and CSP development. Furthermore, electrical energy generated with solar technologies cannot currently be applied to all sectors with energy gaps; in the near term, household heating and cooking as well as transportation energy needs may be best met with more efficient combustion devices using cleaner fossil or bio-derived fuels. This analysis attempts only to estimate the scale of the energy deficits across Africa and the availability of one of the many energy resources available to address these deficits.

ENERGY GAP IN AFRICA

- Energy gap defined as difference between a country's energy needs and current consumption.
- 1,500 W per person (13,140 kWh/capita-year) across all sectors was selected as an energy consumption baseline or target (average of values proposed by Goldemberg 1985 and Spreng 2005)
- 2005 total consumption data reported by the Energy Information Administration (EIA) were used in this analysis (2008).
- Population and other data were obtained from the Human Development Report (UNDP 2007); for countries with data not reported in the Human Development Report, data from the World Factbook were used (CIA 2008).
- Only nationally aggregated numbers were used, so no information on energy equity within countries can be derived here.

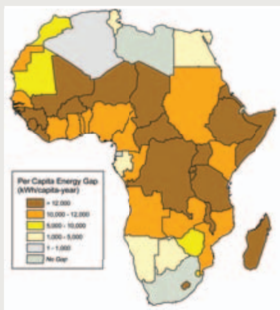

Figure 1. Energy Gap in Africa

Only three African countries did not show an energy gap: Equatorial Guinea, Libya, and South Africa averaged 30,276, 37,028, and 30,818 kWh/capita-year, respectively. Of the remaining countries, the energy gap ranged from 437 kWh/capita-year in Algeria to 13,053 kWh/capita-year in Chad. Twenty-one of the 48 countries included in this analysis average less than 1,140 kWh/ capita-year, or less than 9% of the benchmark value of 13,140 kWh/capita-year (see **Figure 1**).

PV-GENERATION POTENTIAL

The technical PV electricity-generation potential in Africa was estimated using the 40-km resolution latitude tilt resource data developed at NREL. This dataset describes the solar energy that reaches a fixed axis, north/south-facing flat plate collector, tilted toward the sun at an angle equal to that location's latitude in kWh/m²-day. These data (TILT) were used to estimate the electricity-generating potential using the following equation.

$$(\text{PV energy})_A = (\text{Productive Land Area})_A * (TILT)_A * \eta * 365 \text{ days}$$

This analysis estimated the productive land in each country as 1.5% of the total land area (5% of land available for PV installation, of which 30% would be covered with panels) and a conversion efficiency (η) of 10%.

The country-level generation potential ranged from 33 TWh/year in the Gambia to 8,700 TWh/year in Sudan. **Figures 2 and 3** show the total PV electricity-generation potential and the ratio of this potential to the total energy gap by country. In Rwanda and Burundi, the theoretical PV-generation potential was less than the energy gap, with potential equal to 57% and 75% of those energy gaps, respectively.

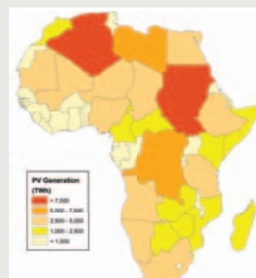

Figure 2. Total PV Electricity-Generation Potential in Africa

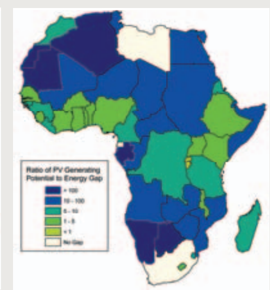

Figure 3. Ratio of PV Electricity-Generation Potential to Total Energy Gap

ESTIMATING CONCENTRATING SOLAR POWER-GENERATION POTENTIAL

To determine the CSP electricity-generation potential in countries across Africa, this analysis used the 40-km resolution direct normal irradiance (DNI) data developed by NREL. This dataset describes the amount of direct solar radiation reaching a device that tracks the sun's movement over the course of the day, which is the radiation component relevant to CSP applications.

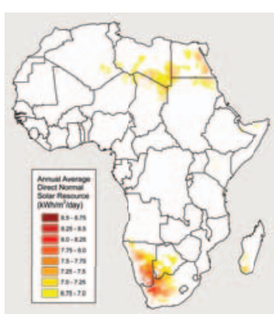

Figure 4. Land Areas in Africa that Meet CSP Potential Development Criteria

Analysis constraints applied:

- Annual average DNI resource of 6.75 kWh/m²-day or greater
- Terrain slope less than or equal to 1%
- Excluded all urban areas, water bodies, and protected areas
- Remaining land assumed an installed capacity of 50 MW/km² operating at a 30% capacity factor
- Yields theoretical maximum potential of CSP generation in terawatt hour (TWh) under these parameters

Only 17 countries demonstrated CSP electricity-generation potential based on the filtering criteria applied in this analysis. The annual generation potential ranged from 7 TWh/year in Eritrea to 40,500 TWh/year in Libya. **Figure 4** shows the land areas in Africa that meet all of the potential development criteria. CSP potential is not as widespread as PV potential across Africa; but where CSP potential does exist, the generation potential is substantial because of the nature of the technology. The land area identified in the figure represents an electricity-generating potential of almost 215,000 TWh/year.

POTENTIAL AVOIDED GHG EMISSIONS

Avoided GHG emissions by meeting each country's energy gap with renewable energy technologies (RETs), such as solar technologies, were estimated using each country's current CO_2 emissions profile.

- 2005 CO_2 emissions were obtained from EIA for all African countries
- 2005 GHG emission factors were estimated by dividing total emissions by total consumption
- The business-as-usual (BAU) scenario assumed that energy gaps would be met using technologies with similar emission factors to those calculated for 2005
- These additional emissions would be avoided if RETs were used in place of the historical energy technologies to meet the energy gap

Meeting the energy gap under the BAU scenario would increase annual emissions by 1,909 MMT-CO_2, nearly tripling the 2005 emissions of these 45 countries (1,035 MMT CO_2, EIA). Deployment of RETs to meet energy demands across Africa could avoid GHG emissions and reduce climate vulnerability in regions heavily reliant on hydropower. While nontechnical barriers to deployment of PV and CSP technologies significantly impact energy choices, it is still very likely that solar-based renewable energy technologies can and will play a significant role in closing the energy gap.

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