Renewable Energy in Developing and Developed Nations: Outlooks to 2040

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With increasing concern over the environmental effects of burning fossil fuels, the call for a more sustainable resource base has never been louder. Both developed and developing nations depend on an assortment of primary energy sources to produce electricity, like coal, natural gas, biomass, oil and renewables. This study addresses the problem of transitioning to a renewable energy-based electricity generating infrastructure. To do this, we explored the current and future state of energy affairs in the United States and developing countries of Kenya, Morocco and South Africa. From this research, we created a framework that can be applied to any country to determine the required capacity installations per year until 2040 in order to generate nearly 100% of electricity with renewable sources. This framework utilizes estimates of future electricity consumption per capita to project total electricity demand in 2040. From here, this demand is allocated to a variety of renewable energy generating sources. The framework was then applied to the four study countries, demonstrating how their potential capacity for renewable technologies and energy efficiency measures can transform their energy sectors into more sustainable, diverse resource bases for electricity generation.

INTRODUCTION

Traditional, non-renewable sources of electricity like coal, natural gas and oil, supply a vast majority of the world's electricity demand. However, these sources are criticized for intense greenhouse gas emissions, availability concerns, economic feasibility uncertainties, and association with a dependence on foreign energy supply (Hidayatullah et al., 2011). Renewable sources, like solar photovoltaic (PV), wind, hydroelectric, geothermal and biomass, are becoming attractive options because of their low carbon impact, indefinite supply, price stability in the energy market and economic benefits. However, renewables have shortcomings as well, like high initial costs, an intermittent energy supply, and inability to supply a stable, base load electricity demand (Giraldo et al., 2014; Hidayatullah et al., 2011).

Studies have shown that energy availability and economic growth are inextricably linked (Neto et al., 2014). Ohler and Fetters (2014) contend that renewable energy technologies hold important roles in future energy use and economic prosperity, and subsequently lead to a faster transition towards a developed society. The problem lies in the transition from fossil fuels to renewable energy sources for electricity generation. Therefore, this study aimed to create a universal framework that 1) outlines the required, capacity installations per year until 2040 to generate 100% of electricity demand through five renewable energy sources, and 2) can be applied to all countries, regardless of their stage of development, socioeconomic prosperity, and current state of energy affairs.

We tested this framework with four countries of interest. The resulting provisional national energy "blueprints" integrated current plans for capacity upgrades with potential renewable energy capacity, and harnessed them both to phase out coal, natural gas and oil for electricity generation completely. Working towards these types of "idealized" plans can create positive, incremental changes in how electricity is generated, even if the ultimate goal is not fully reached within the set time frame. The information and conclusions offered in this study create only one path of many that individual countries can possibly take, and are encouraged to be expanded by individual perspectives and considerations.

METHODOLOGY

The study focused on Kenya, Kingdom of Morocco, the Republic of South Africa, and the United States of America. These countries were chosen because they reflect varying stages of economic development, current electricity generation situations, and potential for renewable energy technologies. Statistics from 2012 regarding electricity production, consumption, imports, exports, and electricity access were compiled to provide a "snapshot" of each country's energy situation. The year 2012 provided the most recent, complete data set for all four countries. Data was collected from publically available databanks like the International Energy Agency (IEA), Energy Information Administration (EIA), Central Intelligence Agency World Factbook, and the World Bank. Then, various government reports and investment agency statements were examined to determine the potential for renewable energy capacity that each country established based on their geographic and geologic features. Finally, we examined peer-reviewed journal articles accessed through the University of Florida Libraries about current and upcoming energy efficiency technologies.

Using the background information collected from the statistics and literature review, we estimated per capita electricity use in 2040 and scaled it up to the projected population size in 2040 using predictions from the U.S. Census Bureau (2013). We calculated the total electricity demand in 2040, and formulated an array of renewable energy sources unique to the country that would meet the projected electricity needs. This is the framework that can be applied to all countries to create their blueprint for a nearly 100% renewable future. Existing nuclear power facilities and planned capacity installations currently under construction were included in the blueprint. However, nuclear capacity expected to be decommissioned in this time period was excluded.

The following subsections provide a brief background on the findings, regarding each country's energy situation and potential capacity installations, and short overviews of energy efficiency technologies utilized in each blueprint.

Current Situation and Potential Capacity

Kenya. Kenya is a developing country with 43.4% of its population below the poverty line. Only 18% had access to electricity in 2012, with the remaining population depending on biomass and waste combustion for heating and cooking (EIA, 2014c). Kenya generated 7.6 million MWh of electricity in 2012, 68% from renewable sources and 32% from oil. They rely most heavily on hydroelectric and geothermal, with less than 4% of consumed electricity generated by wind or solar (EIA, 2014c). Kenya neither produces nor consumes natural gas, and their coal industry is not used for electricity generation. Electricity production is irregular, marked by frequent blackouts during peak times when demand outpaces supply.

Kenya's challenge is to expand the distribution of a reliable electricity supply to its citizens while maintaining and expanding current renewable energy capacity. Financial investments by the African Development Bank, International Finance Corporation, and World Bank aim to expand Kenya's renewable energy sector though the Scaling-Up Renewable Energy Program (SREP) enacted in 2011 (ERC, 2011). As part of SREP and Vision 2030, the goal for generating capacity in 2030 is 23,000 MW (1). In 2012, Kenya had an electricity generating capacity of 1,840 megawatts (MW) (EIA, 2014g). To meet these goals, Kenya plans a 50-fold increase in geothermal capacity and small-scale distributions of solar, wind and hydropower to spread access to electricity within an efficient grid system. (ERC, 2011).

Morocco. Morocco is a developing nation that currently imports over 90% of their energy needs because the region lacks oil and natural gas reserves, and the strong solar and wind potential has not yet been utilized (CIF, 2013). Morocco consumed 25.4 million MWh of electricity in 2012, composed of roughly 70% fossil fuels, 20% hydroelectric plants, and 4% renewable technology (CIA, 2012a; EIA, 2014e). 98% of the population has access to electricity (EIA, 2014e).

Morocco's main challenge is weaning off foreign fuel sources, and supplying a reliable, domestic source of electricity production. Relying on fossil fuel imports causes financial stress, an unpredictable energy supply, and substantial greenhouse gas emissions (IEA, 2014). Due to its prime location near the Sahara desert, Morocco has been emphasizing solar and wind energy. In 2012, total electricity generating capacity was 6,763 MW (EIA, 2012), with less than 4% coming from renewable sources. In 2020, the goal is 42% renewables by increasing each solar, wind and hydropower capacity by 2 GW each (Moroccan Investment Development Agency, 2014). Their National Energy Strategy, set into effect in 2009, established priorities for the energy sector: emphasize energy efficiency, expand renewables and encourage foreign investment (IEA, 2014). As of a report published in late 2013, Morocco is on time with these goals.

South Africa. South Africa is a middle-income country that generates 90% of its electricity from coal-fired power plants. As a result, it is the largest emitter of carbon dioxide in Africa, and 14th largest in the world, according to 2011 estimates (EIA, 2014h). Estimates from the CIA (2012b) indicate that 82.7% of the population had access to the over 234.2 million MWh of electricity consumed in 2012. The remaining 10% of electricity supply is divided evenly between nuclear and hydroelectric dam generation (EIA, 2014h).

Reducing greenhouse gas emissions and stabilizing the electricity supply are two major goals for South Africa (EIA, 2014h). Therefore, the country is planning to diversify its primary energy sources and expand total production by 20% by 2025 (EIA, 2014h). The Integrated Energy Plan (IEP), launched in 2011, aims to increase renewables, primarily wind and solar, from 203 MW to 18,200 MW of capacity in 2030. In addition, nuclear power would expand from 1,920 MW to 9,600 total capacity by 2030 (EIA, 2014h). According to South Africa's leading electricity producer, Eskom, current progress of these projects is not well documented, and ranges from initial planning stage to completed (Eskom, 2015).

The United States. The United States consumed over 4 billion megawatt hours (MWh) of electricity in 2013. Coal was the leading source of electricity generation, with 91% of our domestic production comprising 39% of U.S. demand. (EIA, 2014a). Natural gas was the second leading source, providing 28% of electricity needs to the residential and commercial sectors (EIA, 2014b). New technologies, like hydraulic fracturing, allowed the U.S. to produce 93%

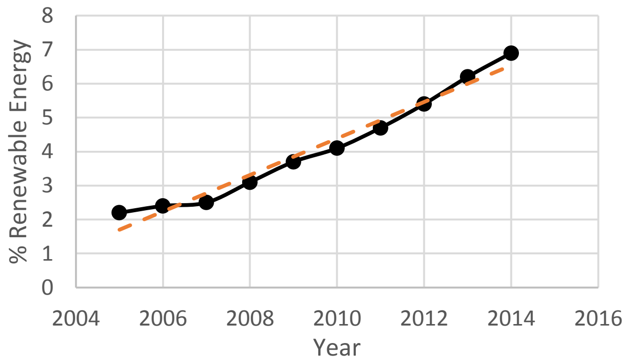

Figure 1. The percent of U.S. electricity generated by renewable sources in 2005-2014. A linear growth of renewable capacity leads to 20.5% market share by 2040, higher than the EIA Outlook projection of 16%. Exponential growth would significantly increase this projection.

of the gas it consumed in 2012 (Chen et al., 2014; EIA, 2014a).

The remaining 35% of electricity generation was split between nuclear power and renewable energy sources. In 2013, domestic nuclear power generated 22% of the nation's electricity (EIA, 2014i). Renewable energy provided 13% of electricity demand, consisting of 53% hydropower, 32% wind, 12% biomass, 3% geothermal and 2% solar (EIA, 2014b). The United States' challenge is to improve energy efficiency and reducing fossil fuel combustion for electricity generation.

The following projections for the United States' electricity demand were gathered from the EIA Annual Energy Outlook 2012, a quantitative study that projects long-term annual trends in energy supply, demand, and prices to the year 2040. Renewable technologies are expected to grow 67%, comprising only 16% of national electricity generation in 2040. However, further research shows renewable capacity has been growing consistently since 2005 (Figure 1) (EIA 2015). A linear trend suggests that the 2040 market share is 20.5%, however, exponential growth may occur in a favorable legislative and economic climate.

Natural gas is anticipated to surpass coal to become the largest share of electricity generation at 35% due to ample reserves, low-cost extraction methods and low natural gas prices. However, fluctuations in natural gas prices may shift focus to other energy sources. Natural gas is also projected to compensate for the retirement of 19% of the coal-fired electricity generating capacity of 2012. 50 GW out of 310 GW of coal-fired capacity is planned to be decommissioned by 2020 (EIA, 2014i).

Upcoming Technologies

Proper utilization of the following technologies may assist countries towards a more sustainable resource base.

Renewable Energy. Renewable energy sources can be used indefinitely when harnessed sustainably. The feasibility of each source depends on each country's climatic variations, geologic features, and landscape setting. The Sahara provides an ideal setting for vast solar array panels, whereas the hydrothermal vents in the Great Rift Valley provide extensive potential for geothermal power in Kenya.

Smart Grid and Smart Meter. The "grid" enables power generators to transmit electricity to consumers through power lines and transmission stations. With the emergence of renewables, existing grids need to be updated to integrate power from solar photovoltaic cells, wind turbines, etc. A smart grid would be able to incorporate these sources, transmit electricity efficiently, retain consumer affordability, reduce greenhouse gas emissions and reduce power outages (Fadaeenejad et al., 2013; Hidayatullah et al., 2011; US DOE). Additionally, smart meters (in-home devices to control electricity use based on price), reducing use during peak-demand (therefore high-cost) times. This reduces strain on the system and improves overall efficiency (Cook et al., 2012).

Distributed Generation. With a smarter grid system comes the ability to integrate electricity from small-scale solar arrays, wind turbines and fuel-based generators (Ganesan et al., 2012). Employing these smaller, decentralized sources of electricity, known as Distributed Generation (DG) systems puts less strain on a centralized grid and provide a back-up supply of electricity during peak load times (Hidayatullah et al., 2011). However, these small systems may not be comparable in reliability, cost effectiveness or environmental impact (Ganesan et al., 2012). Still, DG systems provide household-scale electricity generating stations, so rural communities may be able to have access to electricity without being connected to the central grid.

Hydrogen Batteries. Employing hydrogen battery storage may reduce the variability of wind and solar systems (Rugolo, 2010). During times of excess supply, energy is "stored" in the form of hydrogen through electrolysis, and then "released" during times of low wind or sunlight (Chen et al., 2014; Blankenship, 2004). Advanced hydrogen storage is still in its infancy. However, copious literature regarding general battery storage for solar and wind DG systems suggests widespread application and inexpensive costs on the near horizon.

Energy Efficiency. Energy efficiency is a crucial part of sustainable development strategies. Roughly 30% of residential electricity consumption in the United States can be eliminated by behavioral changes and simple, low- to no-cost upgrades around the household (EIA, 2014b). Simply put, reducing electricity use will require less generating capacity expansions. Household energy reduction strategies are outlined in Table 1. Similar measures can be implemented in commercial and industrial buildings when applicable.

Table 1. Residential energy efficiency measures to reduce electricity demand.

No Cost/Low Cost
Turn lights off when not in use
Unplug phantom loads
Adjust A/C and heating temperatures
Switch to CFL or LED bulbs for lighting fixtures
Higher Cost
Upgrade to Energy Star Appliances
Upgrade to more efficient HVAC system
Replace windows with double pane and alloy frames
Build house to harness natural lighting
Install solar PV array

RESULTS

Applying our framework calculations to each country provided the total electricity use in 2040 given in Table 2. Using average capacity factors for each source, we then established the generating capacity installations required to meet the 2040 blueprints (Table 3).

Kenya

The proposed 'blueprint' for Kenya includes a distributed network of renewable sources, led by geothermal power from the Great Rift Valley (Figure 2A). Kenya would benefit from energy efficiency measures, distributed generation, and implementation of micro-grids. These smaller, decentralized grids would allow individual homes and rural towns to access electricity, without accruing extensive costs to power scarcely populated areas. Kenya has to install 400 MW or less of each source each year until 2040 to make this proposed plan a reality (Table 3).

Morocco

Morocco's blueprint includes a heavily solar- and wind-based sector, with upgrades in energy efficiency, smart grid technology and battery storage. Morocco' solar and wind installations (Table 3) are the only two major inputs to their energy generation, apart from relatively small inputs of hydro and biomass power each year (100 MW and 120 MW, respectively). As a result, the 2040 blueprint provides three times as much energy per capita than in 2012.

South Africa

South Africa is focusing on diversifying and stabilizing energy resources, and capitalizing on the areas enormous solar and wind energy potential (Figure 2C). The technologies that would benefit South Africa include energy efficiency, smart grid, smart meter, distributed generation, and hydrogen storage. Population growth is expected to be minimal, so total electricity production increases only slightly (Table 2). So far, South Africa requires the largest installations of solar and wind capacity per year at 1400 MW and 1200 MW respectively. However, their IEP already dictates substantial installations planned for completion in 2030 that match or exceed the ones outlined in this study.

The United States

Employing the electricity breakdown by source in Figure 2D would generate enough electricity to power American homes with a distributed generation of solar PV, wind, hydropower, geothermal, biomass, and existing nuclear capacities. It is crucial for the United States to utilize smart grid, smart meters, distributed generation and hydrogen battery storage. Electricity consumption per capita is expected to decrease with improved efficiency, from 12,200 to 8,000 kWh/year (Table 2). Still, about 12,500 MW of solar and 18,000 MW of wind capacity must come online each year to meet the 2040 goals (Table 3). Additional expansions in hydropower and geothermal would offset the net capacity decrease in nuclear as aging plants are decommissioned.

Table 2. Framework applied to the four study countries to project total electricity use in 2040. The per capita use in 2040 was estimated by comparing per capita use of developed countries outside of this study with the "goal" quality of life and ideal energy use of our four study countries. Kenya, Morocco and South Africa all increased in per capita use, while the United States' per capita use declined to a more reasonable rate for a developed nation.

Country	2012 Electricity Use (MWh)	2012 Population	2012 Per Capita (MWh/yr)	2040 Projected Per Capita (MWh/yr)	2040 Projected Population	Calculated Electricity Use (MWh)
Kenya	6,329,000	41,944,000	0.15	2.0	64,059,000	128,118,000
Morocco	25,274,000	31,968,000	0.8	2.5	40,267,000	100,667,500
South Africa	218,202,000	49,004,000	4.5	5.0	49,071,000	245,355,000
United States	3,882,599,000	311,592,000	12.5	8.0	380,016,000	3,040,128,000

Table 3. Required capacity installations for each country by source, in MW, per year until 2040.

Source	Kenya	Morocco	South Africa	United States
Solar PV	400	800	1,400	12,512
Wind	320	572	1,196	18,016
Hydroelectric	90	100	52	392
Geothermal	352	0	0	32
Biomass	160	120	160	40
Nuclear	0	0	282	-412
Total (per year)	1,322	1,592	3,090	30,580

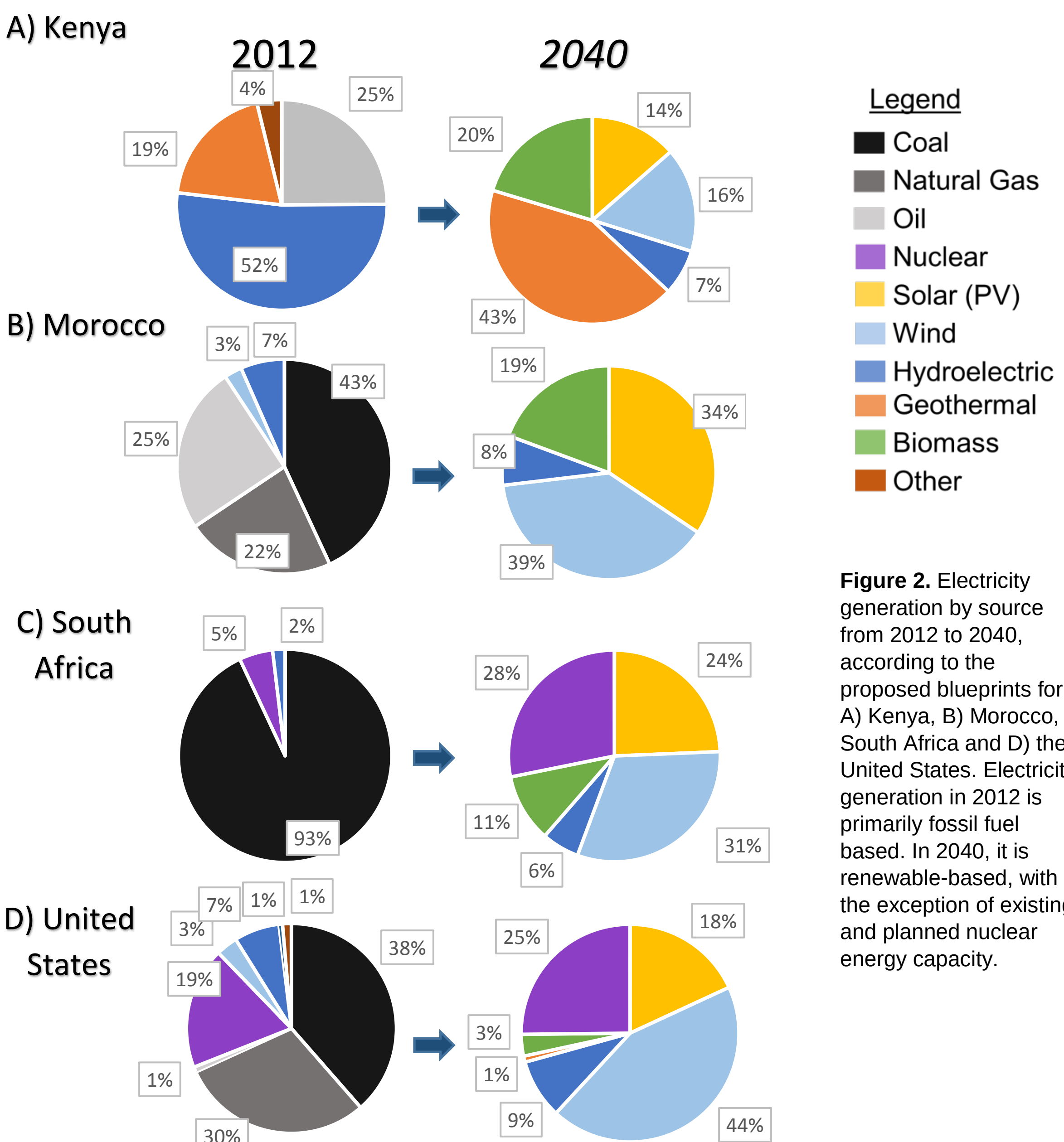

Figure 2. Electricity generation by source from 2012 to 2040, according to the proposed blueprints for A) Kenya, B) Morocco, C) South Africa and D) the United States. Electricity generation in 2012 is primarily fossil fuel based. In 2040, it is renewable-based, with the exception of existing and planned nuclear energy capacity.

DISCUSSION

Working towards the capacity installations presented here may lead to dramatic socioeconomic progress in developing countries, like widespread access to electricity and clean water, improved health from burning less biomass in poorly ventilated homes, better opportunities and equity for women, and increased education and literacy rates in women and children (EIA, 2014g). In developed countries, this transition would yield reductions in greenhouse gas emissions, fewer air and water pollutants, better health in high-density areas, and reduced environmental impact from coal and natural gas mining. Overall, the transition to a more sustainable, renewable energy-based electricity sector leads to more advanced nations and a better quality of life for their residents.

The availability of financial capital and outside support in the developing nations of Kenya, South Africa and Morocco will significantly influence the direction of energy resources used for electricity production over the next 25 years. In developed countries, the transition away from fossil fuels is highly dependent on favorable legislative mandates, economic condition and price volatility of competing sources. Since renewable energy is an emerging field, there is no set political framework to implement or regulate these technologies. Policy actions like tax credits, subsidies, rebates and financial assistance could potentially shift focus towards renewable technologies, increasing their competitiveness in contemporary market conditions (EIA, 20014i).

The limitations of this study include its scope, focusing on four countries, and the potential errors and variation in data reporting from federal and private organization sources. Additionally, the unpredictability of population growth rates, electricity demand, and outside policies or economic factors could alter projections significantly, so the conclusions drawn here should be taken to reflect current market conditions.

Augmented response toward renewable technology could significantly alter the electricity sector within the next 30 years. There may not be a single solution to solve the energy crisis in the U.S. and abroad, but a strong combination of innovative technologies may provide a lasting, sustainable approach to electricity generation.

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