The High 5

Climate Change and Renewable Energy Generation in Africa

Boris Odilon Kounagbè Lokonon and Adeleke Oluwole Salami

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Abstract

This paper contributes to the economics literature on renewable energy generation by investigating climate-change impacts on renewable energy generation in Africa (with special focus on hydropower generation as it is the main renewable source of power in the continent). The analysis includes 51 African countries over the period 1996-2012. The econometric approach consists of estimating a model of the determinants of hydroelectricity generation, using dynamic panel framework (system General Method of Moments). The findings suggest that lagged hydroelectricity generation and crude oil price are the main drivers of hydroelectricity generation. Flood occurrence appears to hamper hydroelectricity sector development. We advocate for international commitment in terms of reducing the emissions of greenhouse gases. Moreover, African countries should continue investing in renewable energy technologies to achieve a low-carbon energy mix. Higher taxation or reduction in subsidies of crude oil based technologies could be beneficial to the development of the renewable energy sector.

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Adeleke O. Salami

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Boris Odilon Kounagbè Lokonon and Adeleke Oluwole Salami

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[1] Boris Odilon Kounagbè Lokonon is a Researcher and Lecturer at Faculté des Sciences Economiques et de Gestion (FASEG), Université de Parakou, Benin. Adeleke O. Salami (a.salami@afdb.org) is a Senior Research Economist at the African Development Bank, Abidjan.

1. Introduction

Energy is of paramount importance for economic growth. Energy is essential for modern communication, development of the industrial sector, and provision of public services such as streetlights, improved education and health care (Ahlborg *et al.*, 2015). In Africa, there is a huge gap between energy supply and demand. Despite the importance of energy for economic growth, production of non-renewable energy releases greenhouse gases (GHGs) in the atmosphere. The anthropogenic GHGs are partly responsible for climate change (IPCC, 2013). Climate change is one of the biggest challenges that mankind faces, resulting in the loss of livelihoods (AfDB 2013; IPCC, 2014; Kirchner and Salami, 2014). Therefore, there is growing consensus that meeting energy demand should be done in a secure and sustainable way, with the least possible GHG emissions. Consequently, renewables are considered to play a key role towards achieving a low-carbon energy mix.

Many papers have proven the importance of renewable energy for economic growth apart from its environmental benefits (e.g., Inglesi-Lotz, 2016; Tugcu et al., 2012; Apergis and Payne, 2011; Kirchner and Salami, 2014). However, Menegaki (2011) found evidence for a neutrality hypothesis between economic growth and renewable energy in Europe, owing partly to the uneven and insufficient exploitation of renewable energy sources across the European continent. Renewable energy sources include biomass, hydropower, wind power, direct solar energy, and geothermal energy. Climate change is expected to have influence on renewable energy generation (Jerez et al., 2015; Pasicko et al., 2012). Its impacts on energy production are mainly through the potential reduction in precipitation, and the increased evaporation due to expected increase in the mean temperature (Pasicko et al., 2012).

Although climate change is expected to affect renewable energy generation, the economics literature on climate change has largely overlooked this area of research (Eyraud et al., 2011). The existing literature is more in the direction of the determinants of energy consumption, either total or renewable energy (e.g., Akar, 2016; Ahlborg et al., 2015), energy supply security (e.g., Erdal, 2015), and renewable electricity technologies (Pohl and Mulder, 2013; Brunnschweiler, 2009). However, few papers have assessed the impacts of climate change on renewable energy generation (Jerez et al., 2015; Pasicko et al., 2012), and these papers mostly relate to Europe. Therefore, there is a literature gap regarding the impact of climate change on renewable energy sector development in Africa. It is worth noting that renewable energy is often analyzed within the framework of environmental technological change, a necessary though not sufficient condition for transition to sustainability (del Río González, 2009).

Due to the advocacy of the lighting and powering of Africa through renewables, it is of paramount importance to assess the extent to which climate change affects and will continue affecting renewable energy generation in the African continent. Thus, this paper aims to assess climate-change impacts on renewable energy generation in Africa (with special focus on hydropower generation as it is the main renewable source of power in the continent), using an econometric model estimated within the dynamic panel framework to account for the likely dynamic development over time of the renewable energy sector. This econometric framework allows also to account for the likely endogeneity from explanatory variables (e.g., Gross Domestic Product (GDP) per capita, and Foreign Direct Investment (FDI) inflows), meaning they are correlated with past and possibly current realizations of the error (Roodman, 2009). It is important to investigate the extent to which climate change may have an impact on the energy exploitation from renewables, as most of the renewable energy sources are affected by climate conditions (Pasicko et al., 2012).

Moreover, power system planning requires a long-term approach owing to the fact that the planning and construction processes of hydropower plants take a long period of time and, once built, they usually have long operation life time (Pasicko et al., 2012; Pedraza, 2014). Therefore, according to the current authors, investment decisions in new hydropower plants need to be economically justified and account for the information about climate change. However, to the best of our knowledge, there is a limited number of studies that have investigated quantitatively the extent to which climate change could affect renewable energy generation in the African continent. Therefore, this paper aims to contribute to the literature on climate- change impacts on renewable energy sector development in the African continent.

The remainder of the paper is organized as follows. Section 2 is devoted to the stylized facts on renewable energy and climate change in Africa. The determinants of renewable energy investments and generation are presented in section 3. Material and methods are presented in section 4. Results and discussion are presented in section 5. Section 6 concludes the paper.

2. Stylized Facts on Renewable Energy and Climate Change in Africa

2.1. Renewable Energy in Africa

Although Africa is endowed with large renewable energy resource potential, this potential is not yet fully exploited. The African continent is endowed with more than half of the world’s renewable energy potential (AfDB, 2016a; Kirchner and Salami, 2014). The continent has

1,750 terawatt-hours (TWh) potential of hydropower and 14,000 megawatt-hours (MWh) of geothermal potential, with only 5% and 0.6% of these potentialities that are used respectively (UNIDO, 2009). In Africa, hydropower constitutes a fifth of the power capacity, but not even a tenth of hydropower potential has been used (AfDB, 2016a). Africa is also endowed with significant technical potential of solar, wind, and geothermal energy (AfDB, 2016a). As illustration, in 2013, renewable energy constituted 17% of total energy generation in Africa (AfDB, 2016a).

Table 1 shows the evolution of overall renewable electricity generation in Africa and in major producing countries of the continent. When considering the whole Africa, an increasing trend in renewable electricity generation is observed from 1980 to 2012. The same pattern of increasing trend in renewable electricity generation observed for the whole continent is noted for the individual countries. It is worth noting that a decrease is observed during the middle of the 1980s when all countries experienced a decrease in renewable electricity generation except Algeria, Angola, Congo, Cameroon, Democratic Republic of Congo, Ethiopia, Gabon, Nigeria, and Tunisia.

Table 1: Total net renewable electricity generation (billion kilowatt-hours)

	1980	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**
Africa	60.243	47.0486	55.99073	60.2142	77.0032	92.24807	115.8006	116.8446	119.5696
Algeria	0.248	0.639	0.134	0.191	0.053	0.549	0.172	0.497	0.616
Angola	0.53	0.6	0.718	0.891	0.903	2.197	3.666	3.967	3.94
Cameroon	1.35	2.295	2.609	2.725	3.408	3.734	4.276	4.412	4.558
Congo	0.099	0.288	0.485	0.348	0.292	0.351	0.426	0.783	0.813
Congo (DRC)	4.199	4.975	5.569	6.097	5.939	7.319	7.774	7.769	7.852
Côte d'Ivoire	1.345	1.344	1.309	1.766	1.746	1.533	1.711	1.865	1.837
Egypt	9.699	8.01905	9.8751	11.3092	13.6972	13.0702	14.607	14.685	14.721
Ethiopia	0.473	0.747	1.088	1.414	1.635	2.805	4.9003	6.2173	6.5943
Gabon	0.257	0.66	0.701	0.792	0.802	0.811	0.905	0.839	0.908
Ghana	5.276	2.996	5.664	6.036	6.544	5.573	6.926	7.485	7.99
Morocco	1.487	0.465	1.184	0.605	0.775	1.1751	4.0921	2.8631	2.3431
Nigeria	2.724	2.978	4.343	5.445	5.686	7.69	6.31	5.824	5.602
South Africa	0.992	0.624	1.01	0.529	1.65	1.637	2.427	2.37	2.418
Tunisia	0.023	0.108	0.044	0.041	0.086	0.186	0.189	0.217	0.31

Source: EIA (2015)

On the whole, Angola, Cameroon, Democratic Republic of Congo, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Morocco, Nigeria, and South Africa are the largest renewable electricity producers in the continent. Unlike renewable electricity, biofuel production is very low in the continent. Countries such as Ethiopia and South Africa produce some kinds of biofuel, which amounted to 0.1 and 0.13 thousand barrels per day in 2012 respectively (EIA, 2015).

From Table 2, it appears that most of renewable electricity generation in Africa is from hydropower. Indeed, at least 94% of renewable electricity generation are from hydropower. Therefore, hydropower is the most used renewable energy source (excluding bioenergy) in Africa and has long been an important part of many African power systems (IEA, 2014). Its attractiveness is due to its large-scale of potential development and the low average costs of electricity generated which are lower than any other technology, either renewable or non-renewable (IEA, 2014). Despite this low proportion of non-hydro renewable electricity generation in Africa, an increasing trend is observed. This share increased from 0.22% in 1980 to 5.51% in 2012. Due to these patterns of renewable electricity generation, this paper focuses on hydroelectricity generation as it accounts for at least 94% of renewable electricity generation in the African continent. Hydropower plants are either classified as large or small. Small hydropower plants are those whose capacity is between 1 MW and 50 MW (Mills and Louw, 2016). Accordingly, large hydropower plants are those that are 50MW and above. Large hydropower plants may lead to environmental degradation and, due to that, there is an advocacy for small hydropower projects. Indeed, changes in the natural ecosystems of the areas within which the rivers are located occur with the construction of dams to create reservoirs for hydropower plants (Kalitsi, 2003).

Table 2: Hydro and non-hydro renewable electricity net generation (billion kilowatt-hours)

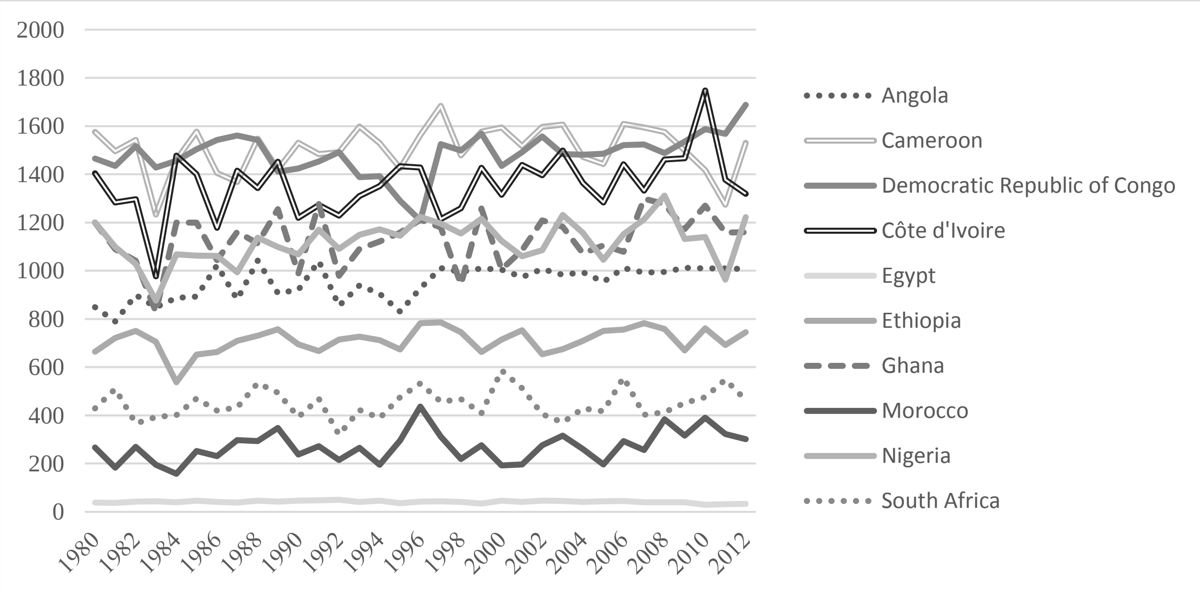
	1980	1985	1990	1995	2000	2005	2010	2011	2012
Hydro	60.11	46.57	54.90663	59.121	74.533	88.47847	109.468	110.035	112.978
	(99.78)	(98.98)	(98.06)	(98.18)	(96.79)	(95.91)	(94.53)	(94.17)	(94.49)
Non-hydro	0.133	0.4786	1.0841	1.0932	2.4702	3.7696	6.3326	6.8096	6.5916
	(0.22)	(1.02)	(1.94)	(1.82)	(3.21)	(4.09)	(5.47)	(5.83)	(5.51)
Total	60.243	47.0486	55.99073	60.2142	77.0032	92.24807	115.8006	116.8446	119.5696
renewable	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)	(100)

Source: EIA (2015)
Note: Percentages are in parentheses.

2.2. Historical Climate Trends and Climate Change in Africa

This section presents the historical climate trends for Africa's key hydroelectricity producers (Angola, Cameroon, Democratic Republic of Congo, Côte d'Ivoire, Egypt, Ethiopia, Ghana, Morocco, Nigeria, and South Africa). In addition, climate projections for the African continent are presented. Climate varies across the landscape in Africa. Some countries appear to be dry while others are wet. Figure 1 shows the evolution of annual rainfall in key African hydroelectricity producing countries over the period 1980-2012, while that of temperature is depicted by Figure 2. Egypt recorded the lowest annual rainfall among the key hydroelectricity producers, due to its geographic position, with less than 100 mm annual rainfall between 1980 and 2012. Annual rainfall in Morocco, South Africa, and Ethiopia is less than 1000 mm, while that in Angola is around that figure. All the remaining countries recorded an annual rainfall greater than 1000 mm. Inter-annual variabilities in rainfall are observed over years in all the countries. However, these are not very clear regarding Egypt, owing to the low annual rainfall amount in that country.

Figure 1: Historical rainfall evolution in key African hydroelectricity producing countries (mm)

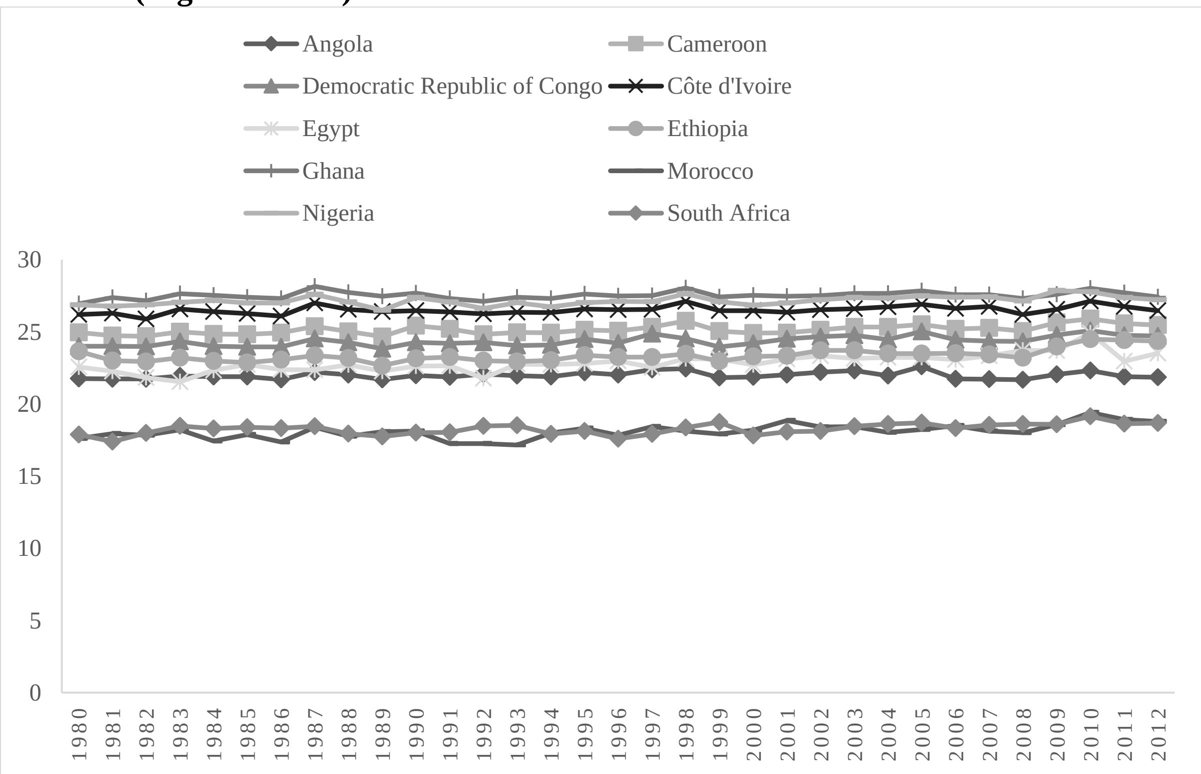


Source: Authors based on World Bank data

Regarding temperature, Morocco and South Africa recorded the lowest temperatures; the mean annual temperature is less than 20 degrees Celsius in these two countries, while West and Central African countries (Cameroon, Democratic Republic of Congo, Côte d'Ivoire, Ghana, and Nigeria) recorded the highest mean annual temperatures. Within the period 1980 to 2012, an increasing trend in temperature is observed, indicating that the climate is getting warm in these African countries. Consequently, the frequency and intensity of droughts have increased in West Africa since 1950 (IPCC, 2013).

A lot of work has gone into simulation and projection of future climate change. For example, a hierarchy of climate models is used to simulate future changes in the climate system, ranging from simple climate models, to models of intermediate complexity, to comprehensive climate models, and Earth System Models (IPCC, 2013). These models make use of a set of scenarios of anthropogenic forcing (IPCC, 2013). According to the IPCC (2013), a new set of scenarios, the so-called ‘Representative Concentration Pathways’ (RCPs) was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. There are basically four RCPs: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. These depict atmospheric CO_2 concentrations higher in 2100 relative to the present day as a result of a further increase of cumulative emissions of CO_2 to the atmosphere during the 21st century (IPCC, 2013).

Figure 2: Historical temperature evolution in key African hydroelectricity producing countries (degree Celsius)



Source: Authors based on World Bank data

Future climate change following RCP2.6 and RCP8.5 (the lowest and highest levels of GHGs forcing) is presented in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2013). It depicts an increase in temperature in the African continent, with the increase being higher with the RCP8.5. The warming is not evenly distributed across the landscape: a part of the Sahel region and a part of southern part of the continent are expected to experience the highest increase in temperature. Regarding precipitation, the changes are more pronounced with the highest GHGs forcing and also unevenly distributed across the landscape. Indeed, some parts of Africa will experience a decrease in precipitation, while others will experience an increase. Decreases in annual runoff are likely in parts of Southern Africa by the end of this century under RCP8.5 scenario (IPCC, 2013). Future increase in extreme precipitation related to the monsoon is very likely in Africa (IPCC, 2013). There is low confidence in projections of a small delay in the West African rainy season, with an intensification of late-season rains. However, the limited skills of model simulations for the region suggest low confidence in the projections (IPCC, 2013). Enhanced summer monsoon precipitation in West Africa; increased short rain in East Africa due to the pattern of Indian Ocean warming; increased rainfall extremes of landfall cyclones on the east coast (including Madagascar) (IPCC, 2013).

3. Determinants of Renewable Energy Investments and Generation

A necessary condition for a transition to sustainability is technological change, although it is not sufficient (del Río González, 2009). Therefore, green investments in the energy sector are advocated for a transition to a low-carbon energy mix, especially with regard to the climate-change threat. A precondition to engage in the most radical forms of environmental technologies consists of attaching high value to environmental protection (del Río González, 2009). Eyraud et al. (2011) argued that green investment is intended either to lower pollution from energy generation, or to decrease energy consumption. Moreover, green investment includes technologies that sequester carbon, owing to the fact that deforestation and agriculture are important sources of carbon emission. Therefore, three main components of green investment are identified in the literature (Eyraud et al., 2011).

(i) Low-emission energy supply which is relative to shifting energy supply from fossil fuels to less polluting alternatives, either for electricity generation (wind, solar, nuclear, hydropower, etc.), or as direct sources of energy (e.g., biofuel);

(ii) Energy efficiency in terms of technologies that reduce the amount of energy required to provide goods and services;

(iii) Carbon sequestration in terms of halting the ongoing deforestation, reforesting, and sequestering more carbon in soils through new agricultural practices.

Large hydroelectricity plants are often excluded from renewable green energy as they lead to environmental degradation. Eyraud et al. (2011) argued that in the case of unavailability of financial data on green investment in the energy sector, investment can be measured from capacity data, which refer to the maximum output of electricity usually in the form of kilowatts (kW) and megawatts (MW).

Two broad categories of drivers of green investment are found in the economics literature, the first including traditional determinants of investment as a whole (e.g., interest rates, income level and growth, and production costs), and the second includes determinants specific to green capital accumulation (Eyraud et al., 2011). Economic growth and income are hypothesized as having “accelerator effect” on the energy sector (demand for energy and investment in the energy sector). Moreover, economic activities cause low levels of environmental degradation at the first stages of development. Then, income per capita and environmental degradation increase with the industrialization until the former reaches a certain level beyond which its growth leads to environmental improvement. This is depicted as the Environmental Kuznets Curve (EKC) hypothesis (Rubio et al., 2009; Stern, 2003; Dasgupta et al., 2002; Stokey, 1998; John and Pecchenino, 1994). Population is also hypothesized to boost energy sector development. Indeed, population is expected to have an impact on renewable energy sector development beyond that of economic growth, owing to the fact that parts of fuel consumption and land use do not pass through formal markets, for instance consumption of fuel woods (Eyraud et al., 2011). Moreover, energy needs increase with population, and require investment in alternative energy sources, especially when fossil fuels are scarce or relatively expensive, and/or when renewable resources are abundant (Eyraud et al., 2011).

Fossil fuel prices have the potential to foster hydroelectricity generation. Indeed, higher fossil fuel prices lower the cost of the electricity generated from renewables relative to that produced from fossil fuel combustion (Eyraud et al., 2011; Newell et al., 1999). Fossil fuel price hikes are shown to lead to boosting innovations in green technologies (Newell et al., 1999). Generation of renewable energy should also depend on production costs. High production costs necessitate lot of investments and therefore could constitute an impediment for renewable energy generation. However, this paper does not account for production costs owing to data availability. FDI net inflows are expected to have a positive and significant impact on hydroelectricity generation. Indeed, FDI is considered as driver of the diffusion of environmental friendly technologies (del Río González, 2009).

Furthermore, renewable energy sector development is also expected to display a dynamic development over time (Brunnschweiler, 2009). Renewable energy generation could be influenced by interest rates. Indeed, high interest rates reveal the relative scarceness of financing and lead to the decrease in investment, especially in investments in renewable energies which are highly capital intensive compared to traditional technologies (Eyraud et al., 2011). Unlike other conventional fossil-based technologies, which incur significant fuel costs, renewable technologies require significant capital expenditure before producing any energy with no added fuel cost (Nepal, 2012). Therefore, the average costs of renewable technologies depend highly on the output levels or scale with marginal cost being very low (Nepal, 2012). It is worth noting that interest rates are not included in the econometric model.

Renewable energy generation depends on climate-related variables. For example, a potential reduction in precipitation, and an increased evaporation due to expected increase in the mean temperature can constitute an impediment to renewable energy generation (Pasicko et al., 2012). Therefore, renewable energy is expected to be positively associated with an increase in rainfall, with the effect being non-linear (an inverted U-shape relationship). A similar relationship to that of rainfall is expected for temperature. Climate shocks and extreme events constitute also an obstacle for renewable energy sector development. With droughts, water inflow in the power plant reservoirs will be very low leading to lowering hydropower generation. Although, more water is beneficial to energy generation, beyond a certain level more water could hamper energy generation. With floods, rivers will overflow leading to the overflow of power plant reservoirs and this will constitute an impediment for hydropower generation. Therefore, floods constitute an obstacle to renewable energy generation. In actual fact, climate change is recognized to affect energy resource endowments, production, infrastructure, and transportation (AfDB, 2016b). The African Development Bank (AfDB) argued that climate shocks such as droughts and floods can severely affect water inflows, which can have a knock-on effect on the power generation capacity of energy production units, and hydropower productivity may be reduced due to droughts and floods (AfDB, 2016b).

4. Material and Methods

4.1. Empirical Model

Following the identified determinants of renewable energy generation, renewable energy generation in Africa is considered as function of income, population, prices of fossil energy sources, FDI net inflows, and geophysical conditions (rainfall, temperature, and climate shocks such as floods and droughts). This paper puts special emphasis on the extent to which a change in climate conditions affects renewable energy generation in the African continent. Therefore, the model specification is as follows:

$$RE_{it} = \beta_1 RE_{it-1} + \boldsymbol{CC}'_{it}\boldsymbol{\beta}_2 + \boldsymbol{X}'_{it}\boldsymbol{\beta}_3 + \varepsilon_{it} \quad (1)$$

where RE_{it} denotes hydropower energy generation, $\boldsymbol{CC}_i$ is the set of climate variables (rainfall, temperature, flood occurrence and drought occurrence), $\boldsymbol{X}_i$ represents the vector of control variables described above, β_1, $\boldsymbol{\beta}_2$, and $\boldsymbol{\beta}_3$ are the coefficients to be estimated, and ε_{it} represents the error terms. It is worth mentioning that climate change is captured by annual total rainfall, annual mean temperature, flood occurrence, and drought occurrence.

Equation (1) is estimated by system General Method of Moments (GMM) (Arellano and Bond, 1991; Arellano and Bover, 1995; Blundell and Bond, 1998) because of its dynamic nature. This econometric framework flexibly accommodates unbalanced panels and deals with multiple endogenous variables (Roodman, 2007). Indeed, lagged hydroelectricity generation, GDP per capita, and FDI net inflows may be endogenous, and not accounting for this endogeneity may lead to biased estimations, because this may violate the orthogonality condition. The GMM approaches are proposed as alternative methods to estimate such dynamic panel models (Arellano and Bond, 1991; Arellano and Bover, 1995; Blundell and Bond, 1998). The three variables hypothesized to be endogenous are then instrumented using the level and first lag of population and crude oil price, the first lag of GDP per capita, and FDI net inflows, and the second lag of the dependent variable. This paper does not account for the likely endogeneity of climate-related variables. Indeed, hydropower plants may be responsible for the increase of the concentration of GHGs and thereby may contribute to climate change. With large hydropower plants, organic matter is blocked from flowing downstream, and the trapped organic matter does not decompose properly due to lack in oxygen. This leads to the release of methane and nitrous oxide into the atmosphere. However, the paper considers that the reverse causality from hydroelectricity generation to climate change is expected to be weak, given the relatively small size of the hydroelectricity sector in Africa.

In the light of the identified determinants of renewable energy generation, we expect the following.

- Lagged hydroelectricity generation to have a positive impact on hydroelectricity generation.
- GDP per capita to lead to a positive influence on renewable energy sector development (accelerator effect).
- Population to have a positive impact on hydroelectricity generation.
- Crude oil price to foster hydroelectricity generation.
- FDI net inflows to have a positive impact on hydroelectricity generation.

- Rainfall to lead to an increase in hydroelectricity generation.
- Temperature to lead to a decrease in hydroelectricity generation.
- Flood occurrence to hamper hydroelectricity sector development. Indeed, too much rainfall could lead to floods (depicting an inverted U-shape relationship between rainfall and hydroelectricity generation) which could damage hydropower plants. Flood occurrence is included to capture the non-linear effect of rainfall on hydroelectricity generation.
- Drought occurrence to also hamper hydroelectricity sector development like flood occurrence.

For robustness check, four alternative specifications of equation (1) are estimated, depending on the inclusion of linear climate variables, and climate shocks (floods and droughts). Due to problems of data availability on climate shocks, Côte d'Ivoire is disregarded in the specification accounting for these. As the time dimension is small (17 years), explicit fixed-effect dummies cannot be included in the model as they might cause bias (Roodman, 2009). Therefore, region dummies and policy dummy are not included in the estimated models. As it is wise to include time dummies to remove universal time-related shocks from the errors (Roodman, 2009), year dummies are included in the model.

4.2. Data and Descriptive Statistics

This paper makes use of hydropower electricity generation as a proxy for renewable energy generation. The data on renewable energy generation are collected from the U.S. Energy Information Administration (EIA).[2] Historical climate data (rainfall and temperature) are collected from the World Bank Climate Change Knowledge Portal[3]. The historical rainfall and temperature data are derived from observational datasets that have been quality controlled climate values from weather stations. Crude oil prices are collected from the International Energy Agency (IEA). The data on climate shocks (floods, and droughts) are collected from the Emergency Events Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters (CRED), in Brussels (Guha-Sapir et al., 2016). GDP per capita, population, and FDI net inflows data are from the World Development Indicators (World Bank, 2015). The period under analysis is 1996-2012 due to data availability on the variables used. Fifty-one

[2] The data are available from: www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=44&pid=44&aid=2

[3] http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu=historical

African countries are included in the analysis (see Appendix) owing to data availability.[4] However, in the specifications that account for climate shocks, Côte d'Ivoire is disregarded due to data unavailability. The hydroelectricity data used have a major limitation in that they do not distinguish between small and large hydropower generation.

The descriptive statistics of the variables are reported in Table 3. The average hydroelectricity net generation amounts to 1.74 billion of kilowatt-hours (KWh). Economic development is still low in the continent as shown by the GDP per capita measured in Purchasing Power Parity (PPP). Accordingly, the average GDP per capita is US$ 4,801.15, with a minimum of US$ 492.61 and a maximum of US$ 42,957.3[5] showing the disparities across countries. The population is unevenly distributed across African countries, with an average of 17.51 million of inhabitants. As for crude oil price, its average amounts to US$ 53.80 per barrel. However, its maximum value is US$ 107.78 with a minimum of US$ 12.52.

African countries are to some extent open to FDI flows. The average FDI net inflows to African countries amount to 5.03% of GDP. However, some countries are preferred destinations of FDI flows as depicted by a maximum value of 89.48% of GDP. It is worth noting that some African countries experienced more disinvestments than new investment inflows as shown by a negative minimum (-5.98% of GDP). The average annual rainfall is 1005.34 mm. The countries do not benefit from the same level of annual rainfall; the minimum annual rainfall is 29.39 mm while the maximum amounts to 2796.7 mm. Like annual rainfall, mean annual temperature varies also across countries in the continent, with some countries being warmer and others colder. The average mean annual temperature amounts to 24.50 degrees Celsius, with a minimum and a maximum of 12.64 and 29.64 degrees Celsius respectively. Some countries do not experience floods and droughts. However, up to seven flood and two drought events are recorded in some countries.

[4] Somalia, Sudan, and South Sudan are not included in the analysis due to data unavailability.
[5] This high GDP per capita measured in PPP is recorded in 2008 in Equatorial Guinea.

Table 3: Descriptive statistics for dependent and independent variables*

Variable	Unit	Mean	Standard Deviation	Minimum	Maximum
Hydroelectric net generation	Billion Kilowatt-hours	1.74	3.17	0	16.78
GDP per capita	PPP, constant 2011 US$	4801.15	6355.76	492.61	42957.3
Population	In millions	17.51	25.35	0.08	168.24
Crude oil price	US$ per barrel	53.80	31.49	12.52	107.78
FDI net inflows	Percentage of GDP	5.03	9.01	-5.98	89.48
Rainfall	Millimetres	1005.34	646.09	29.39	2796.7
Temperature	Degrees Celsius	24.50	3.21	12.64	29.64
Flood occurrence	Number	0.73	1.03	0	7
Drought occurrence	Number	0.14	0.35	0	2

Source: Calculated by the authors based on EIA, IEA, EM-DAT and World Bank data

* Mean estimates, standard deviations, minimum and maximum are calculated based on the countries included in the analysis over the period 1996-2012.

5. Results and Discussion

This section presents the empirical results relating to the estimation of determinants of hydroelectricity generation, using dynamic panel framework (system General Method of Moments). Table 4 reports the estimation results of (four) different specifications of hydroelectricity net generation model.[6] The paper tests the validity of the instruments with the Hansen (1982) *J*-test for over-identifying restrictions, with the null hypothesis being that over-identifying instruments are uncorrelated with the error term. The *p*-values of the Hansen *J*-statistics of all the four specifications are above 0.1, except in Model 1 where it is 0.078. Therefore, this fails to reject the null hypothesis that the instruments are valid (in all the four specifications except for Model 1 which includes only economic variables as regressors). To reduce proliferation of instruments the collapse option is used (Roodman, 2009). Serial correlation is tested using the Arellano and Bond (1991) AR(2) test, and the test is satisfactory. Moreover, the estimated models include robust standard errors. The fourth specification (which accounts for all the variables), includes three statistically significant variables besides year dummies[7] which are: (i) lagged hydroelectricity generation, (ii) crude oil price, and (iii) flood occurrence; this specification is our preferred model. The findings reveal that the coefficient associated with lagged hydroelectricity generation is positive and significant at the 1% significance level in all the four models, and suggest thus that renewable energy sector development displays a dynamic development over time and is consistent with the findings of Brunnschweiler (2009). The direction of the impacts of the regressors on hydroelectricity

[6] Crude oil price is disregarded in Model 1 owing to collinearity.
[7] Year dummies results are not reported, but are available upon request.

generation is consistent across specifications except for FDI net inflows, and temperature. Therefore, the results are robust to the four alternative specifications.

Crude oil price is a determinant in the development of hydroelectricity sector. Indeed, the findings suggest that when climate shocks are included in the model, crude oil price affects positively and significantly at the 10% level of significance in model 3 and at the 5% in our preferred model hydroelectricity generation. The estimated coefficient associated with crude oil price, in our preferred Model 4, is 0.005. Thus, African countries take advantage of higher crude oil price to invest in renewable electricity generation, *ceteris paribus*. This finding is not consistent with Brunnschweiler (2009) who found a negative and non-significant impact of crude oil price on hydroelectricity sector development, but is consistent with Eyraud et al. (2011). Crude oil price increases strengthen the incentives to invest in renewable electricity technologies. Higher crude oil price increases the return to hydroelectricity by raising the relative cost of electricity from fossil fuel. The coefficients associated with the year dummies are positive and significant for some years, depicting that there are time-related effects on the development of hydroelectricity sector.

GDP per capita has a negative and non-significant impact on hydroelectricity generation. This suggests that renewable electricity development in the continent does not depend on economic development, *ceteris paribus*. This may be due to the low economic development in the continent as the poorest countries in the world are found in Africa, especially in Sub-Saharan Africa (SSA). Although the coefficient associated with population is positive, it is non-significant. Therefore, an increase in the number of inhabitants does not affect significantly the development of hydroelectricity sector. Openness to FDI does not affect significantly hydroelectricity generation in Africa. The coefficient associated with FDI net inflows is negative in two specifications – Models 2 and 4 – and positive in Models 1 and 3. These findings suggest that openness to FDI does not significantly facilitate the diffusion of environmental friendly energy technologies in Africa. Indeed, the descriptive statistics of the variables, depicting a negative value of the minimum of FDI net inflows, indicate that some African countries experienced more disinvestments than new investment inflows. This finding is not in line with Pohl and Mulder (2013), who found that increasing FDI lowers the likelihood of non-hydro renewable energy adoption as well as the amount of non-hydro renewable energy produced.

Table 4: Estimation results

	Dependent variable: Hydroelectricity Net Generation			
	Model 1	**Model 2**	**Model 3**	**Model 4**
Lagged dependent variable	0.746***	0.768***	0.686***	0.687***
	(0.112)	(0.145)	(0.158)	(0.189)
GDP per capita	-1.67e-06	-3.13e-06	-2.93e-06	-6.73e-06
	(3.89e-06)	(5.70e-06)	(6.90e-06)	(1.44e-05)
Population	0.017	0.016	0.015	0.011
	(0.018)	(0.020)	(0.018)	(0.020)
Crude oil price		0.001	0.006*	0.005**
		(0.009)	(0.003)	(0.002)
FDI net inflows	0.001	-3.15e-05	0.001	-0.002
	(0.002)	(0.002)	(0.002)	(0.003)
Rainfall		0.001		0.002
		(0.002)		(0.002)
Temperature		0.047		-0.025
		(0.408)		(0.466)
Flood occurrence			-0.191	-0.326**
			(0.119)	(0.157)
Drought occurrence			-0.139	-0.146
			(0.521)	(0.647)
Year Dummies	Yes	Yes	Yes	Yes
Observations	746	746	731	731
Number of countries	51	51	50	50
Instruments	47	47	47	47
AR(1)	0.024	0.048	0.020	0.015
AR(2)	0.750	0.908	0.550	0.667
Hansen test (p-value)	0.078	0.154	0.219	0.663

Notes: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. AR(1) and AR(2) are presented in p-values.

Flood occurrence appears to have negative and significant impact on hydroelectricity generation, except in Model 3 where the impact is non-significant. Therefore, floods constitute an impediment to renewable electricity sector development. The findings suggest that floods are detrimental to the development of the hydroelectricity sector. The estimated coefficient associated with flood occurrence, in our preferred model, is -0.326, suggesting that one additional flood event leads to a drop in hydroelectricity generation of about 0.326 billion of KWh. Therefore, climate change influences hydroelectricity generation in Africa, although it is not easy to attribute any extreme event to human-activity-related climate change, as a wide range of extreme events are expected in most regions of the world, even under unchanging climate (IPCC, 2013). This finding give an idea on the burden of climate change on the development of hydroelectricity sector. Consequently, the increase in the frequency of occurrence of floods will slow-down the efforts of the African countries to increase access to electricity to their citizens, *ceteris paribus*, which access is very low amounting to just over 40%, the lowest in the World (AfDB, 2016a).

Apart from floods, the coefficients associated with the other climate-related variables are found to be non-significant. Annual rainfall has positive and non-significant impact on hydroelectricity generation (Models 2 and 4). This finding suggests that the annual amount of rainfall does not affect hydroelectricity sector development in Africa. This result does not mean that rainfall does not affect hydroelectricity in the African continent, it suggests simply that the total annual rainfall does not significantly affect total annual hydroelectricity generation. However, intra-annual rainfall variability may affect hydroelectricity sector development in Africa. Mean annual temperature influence, in terms of the signs of the estimated coefficients, varies with respect to the specifications, it leads to a non-significant increase in hydroelectricity generation (Model 2) and to a non-significant decrease (Model 4). Like for flood occurrence, drought occurrence has also negative impact on hydroelectricity generation. However, unlike for floods the impact of drought occurrence is not significant.

6. Conclusion and Policy Implications

Despite the importance of energy for economic growth, there is a huge gap between energy supply and demand in Africa. Indeed, energy supply does not meet the energy demand. Moreover, the African continent is endowed with more than half of the world's renewable energy potential, but this potential is not yet fully exploited. Owing to the fact that climate change is one of the biggest challenges that the world faces, resulting in the loss of livelihoods (IPCC, 2014), there is a growing consensus that meeting energy demand has to be in a secure and sustainable way, thus putting emphasis on the role of renewables in achieving a low-carbon energy mix. However, climate change could affect renewable energy production. Access to energy is crucial for the achievement of the Sustainable Development Goals (SDGs), one of the seventeen SDGs being ensuring access to affordable clean energy. Consequently, this paper contributes to the economics literature on renewable energy generation by investigating the extent to which climate change influences renewable energy generation in Africa, and focuses on hydroelectricity generation which is the main source of power in the continent (representing at least 94% of renewable electricity generation), through a system GMM approach. The findings suggest that the main drivers of hydroelectricity generation in Africa are lagged hydroelectricity generation and crude oil price. Flood occurrence appears to hamper hydroelectricity sector development. Therefore, if flood occurrence increases in the coming years (decades), as predicted by IPCC projections (IPCC, 2013), this may have negative influence on hydroelectricity generation in the continent.

We advocate for international commitment towards the decrease in the occurrence of climate shocks and extremes. Indeed, human-induced GHGs are the anthropogenic causes of climate change which are responsible, to some extent, for the increase in the occurrence of climate shocks and extremes (IPCC, 2013). Therefore, a reduction of the emissions of GHGs is required. Moreover, African countries should continue investing in renewable energy technologies to achieve a low-carbon energy mix, owing to fact that the hydroelectricity sector development in Africa displays a dynamic development over time. Indeed, the 21st Conference of the Parties (COP 21) advocated for an increase in investment in renewable energy technologies (IEA, 2015). The findings indicating that high crude oil price leads to the development of the renewable energy sector suggest that higher taxation or reduction in subsidies of crude oil based technologies could be beneficial to the development of the sector. Indeed, global subsidies for fossil fuels are about twelve times higher than the subsidies allocated towards renewable energy, according to analysis by Bloomberg New Energy Finance (Timmons et al., 2014). Therefore, externalities arising from fossil-fuel-based energies could be internalized so that their prices could reflect their full social costs. For instance, countries which are not endowed in oil rely also on generation from oil to supply electricity to the population.

References

AfDB (2013). The African Development Report 2012: Towards Green Growth in Africa, Tunis: African Development Bank Group.

AfDB (2016a). Annual Development Effectiveness Review 2016: Accelerating the Pace of Change, Abidjan: African Development Bank Group.

AfDB (2016b). Annual Report 2015, Abidjan: African Development Bank Group.

Ahlborg, H., F. Boräng, S. Jagers, and P. Söderholm (2015). "Provision of Electricity to African Households: The Importance of Democracy and Institutional Quality", Energy Policy, Vol. 87, pp. 125-35.

Akar, B. G. (2016). "The Determinants of Renewable Energy Consumption: An Empirical Analysis for the Balkans", European Scientific Journal, Vol. 12, No. 11, pp. 594-607.

Apergis, N. and J. E. Payne (2011). "The Renewable Energy Consumption-Growth Nexus in Central America", Applied Energy, Vol. 88, No. 1, pp. 343-7.

Arellano, M. and S. Bond (1991) "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations", The Review of Economic Studies, Vol. 58, No. 2, pp. 277-97.

Arellano, M. and O. Bover (1995). "Another Look at the Instrumental Variable Estimation of Error-Components Models", Journal of Econometrics, Vol. 68, No. 1, pp. 29-51.

Blundell, R. and S. Bond (1998). "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models", Journal of Econometrics, Vol. 87, pp. 115-43.

Brunnschweiler, C. N. (2009). Finance for Renewable Energy: An Empirical Analysis of Developing and Transition Economies. Zurich: CER-ETH – Center of Economic Research, Working Paper 09/117.

Dasgupta, S., B. Laplante, H. Wang, and D. Wheeler (2002). "Confronting the Environmental Kuznets Curve", The Journal of Economic Perspectives, Vol. 16, No. 1, pp. 147-68.

del Río González, P. (2009). "The Empirical Analysis of the Determinants for Environmental Technological Change: A Research Agenda", Ecological Economics, Vol. 68, No. 3, pp. 861-78.

EIA (2015). International Energy Statistics. U.S. Energy Information Administration, Retrieved from www.eia.gov/beta/international/data/browser/#/?pa=000000000000000000000000000005vm&c=200m0021so005h00h9g000000c0k46d000000002ca82c130003g&ct=0&ug=8&tl_id=2-A&vs=INTL.27-12-DZA-BKWH.A&ord=CR&vo=0&v=H&start=1980&end=2012.

Erdal, L. (2015). “Determinants of Energy Supply Security: An Econometric Analysis for Turkey”, Ege Akademik Bakiş / Ege Academic Review, Vol. 15, No. 2, pp. 153-63.

Eyraud, L., A. Wane, C. Zhang, and B. Clements (2011). Who”s Going Green and Why? Trends and Determinants of Green Investment, Working Paper 11/296, Washington, D.C.: International Monetary Fund,

Guha-Sapir, D., R. Below, and P. Hoyois (2016). EM-DAT: The CRED/OFDA International Disaster Database – www.emdat.be, Brussels, Belgium: Université Catholique de Louvain.

Hansen, L. P. (1982). “Large Sample Properties of Generalized Method of Moments Estimators”, Econometrica, Vol. 50, No. 4, pp. 1029-54.

IEA (2014). Africa Energy Outlook: A Focus on Energy Prospects in Sub-Saharan Africa; World Energy Outlook Special Report, Paris: OECD/IEA.

IEA (2015). Energy and Climate Change: World Energy Outlook Special Report, Paris: International Energy Agency.

Inglesi-Lotz, R. (2016). “The Impact of Renewable Energy Consumption to Economic Growth: A Panel Data Application”, Energy Economics, Vol. 53, pp. 58-63.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK and New York, USA: Cambridge University Press.

IPCC (2014). 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. (C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, et al., eds) Cambridge, UK and New York USA: Cambridge University Press.

Jerez, S., I. Tobin, R. Vautard, J. P. Montavez, et al. (2015). “The Impact of Climate Change on Photovoltaic Power Generation in Europe”, Nature Communications, Vol. 6, pp. 1-8.

John, A. and R. Pecchenino (1994). “An Overlapping Generations Model of Growth and the Environment”, The Economic Journal, Vol. 104, No. 427, pp. 1393-1410.

Kalitsi, E. A. (2003). “Problems and Prospects for Hydropower Development in Africa”, Dakar: The Workshop for African Energy Experts on Operationalizing the NGPAD Energy Initiative.

Kirchner, R. and A. Salami (2014). “Promoting a Low Cost Energy Future in Africa”, African Journal of Environmental Science and Technology, Vol, 8, No. 2, pp. 91-98.

Menegaki, A. N. (2011). “Growth and Renewable Energy in Europe: A Random Effect Model with Evidence for Neutrality Hypothesis”, Energy Economics, Vol. 33, No. 2, pp. 257-63.

Mills, L. and A. Louw (2016). Global Trends in Clean Energy Investment, London: Bloomberg New Energy Finance.

Nepal, R. (2012). “Roles and Potentials of Renewable Energy in Less-Developed Economies: The Case of Nepal”, Renewable and Sustainable Energy Reviews, Vol. 16, No. 4, pp. 2200-2206.

Newell, R. G., A. B. Jaffe, and R. N. Stavins (1999). “The Induced Innovation Hypothesis and Energy-Saving Technological Change”, The Quarterly Journal of Economics, Vol. 114, No. 3, pp. 941-75.

Pasicko, R., C. Brankovic, and Z. Simic (2012). “Assessment of Climate Change Impacts on Energy Generation from Renewable Sources in Croatia”, Renewable Energy, Vol. 46, pp. 224-31.

Pedraza, J. M. (2014). “The Use of Hydropower Plants for Electricity Generation in the European Region”, in L. Burke (ed.), Hydroelectricity and Power Electronics: Environmental Impacts, Emerging Technologies and Challenges, New York: Nova.

Pohl, B. and P. Mulder (2013). Explaining the Diffusion of Renewable Energy Technology in Developing Countries, Working Paper No. 217, Hamburg: German Institute of Global and Area Studies (GIGA).

Roodman, D. (2007). A Short Note on the Theme of Too Many Instruments, Working Paper No. 125, Washington, D.C.: Center for Global Development,.

Roodman, D. (2009). “How to do Xtabond2: An Introduction to Difference and System GMM in Stata”, The Stata Journal, Vol. 9, No. 1, pp. 86-136.

Rubio, S. J., J. R. García, and J. L. Hueso (2009). “Neoclassical Growth, Environment and Technological Change: The Environment Kuznets Curve”, The Energy Journal, Vol. 30, No. 2, pp. 143-68.

Stern, D. I. (2003). “The Environmental Kuznets Curve”, Internet Encyclopaedia of Ecological Economics. New York: International Society for Ecological Economics.

Stokey, N. L. (1998). “Are There Limits to Growth?” International Economic Review, Vol. 39, No. 1, pp. 1-31.

Timmons, D., J. M. Harris, and B. Roach (2014). The Economics of Renewable Energy, Medford, MA: Tufts University, Global Development and Environment Institute.

Tugcu, C. T., I. Ozturk, and A. Aslan (2012). “Renewable and Non-Renewable Energy Consumption and Economic Growth Relationship Revisited: Evidence from G7 Countries”, Energy Economics, Vol. 34, No. 6, pp. 1942–50.

UNIDO (2009). "Scaling up Renewable Energy in Africa", 12th Ordinary Session of Heads of State and Governments of the African Union, Vienna: United Nations Industrial Development Organization.

World Bank (2015). World Development Indicators 2015, Washington, D.C.: World Bank.

Appendix: List of countries in the sample

Algeria	Liberia
Angola	Libya
Benin	Madagascar
Botswana	Malawi
Burkina Faso	Mali
Burundi	Mauritania
Cameroon	Mauritius
Cape Verde	Morocco
Central African Republic	Mozambique
Chad	Namibia
Comoros	Niger
Congo	Nigeria
Congo (Democratic Republic of)	Rwanda
Côte d'Ivoire	São Tomé and Príncipe
Djibouti	Senegal
Egypt	Seychelles
Equatorial Guinea	Sierra Leone
Eritrea	South Africa
Ethiopia	Swaziland
Gabon	Tanzania
Gambia, The	Togo
Ghana	Tunisia
Guinea	Uganda
Guinea-Bissau	Zambia
Kenya	Zimbabwe
Lesotho	