RESEARCH ARTICLE

Global CO₂ emission reduction policies and West African electricity system: Case for transformational access [version 1; peer review: 1 approved with reservations]

Abiodun Suleiman Momodu 1, Ahmad Addo 2

1Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Osun, 220005, Nigeria
2The Brew-Hammond Energy Center, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

Abstract
Based on the UN Human Development Index, the West African sub-region holds one of lowest indices in development around the world. There is a glaring need for the sub-region to increase its electricity capacity; however, stringent global CO₂ policies have ‘choking’ effects on the growth of the electricity sector in energy deprived countries, like the West African Member States. This study examines the West Africa electric power sector under a range of technological, economic, and policy-related uncertainties, positing that there is the need to frame policies from the premise of ‘need’ rather than a ‘circumstantial’ perspective, which, in this study, relates to the global policies on CO₂ emission reduction.

Though CO₂ is the inevitable by-product of combusting fossil fuels to generate electricity, it should also be viewed from the perspective of its significant benefits as regards provision of social welfare of individuals. This study evaluated the broad strategies in policy formulation and implementation (top-down versus bottom-up analysis) and applied these strategies to examine investment decision versus pricing regime and electricity system value chain (upstream versus downstream analysis). System dynamics principles were used to forecast what future consumption will look like, which shows that there would be marked increase in demand followed by increased emission without intervention.

This study concludes that global CO₂ policy would need to be re-considered such that energy deprived countries, like those in West Africa, would be able to implement a sustainable development agenda through growth strategy of bottom-up approach to ‘free’ their electricity system for improved living standard, irrespective of climate change issues.

Keywords
Electricity system, West Africa, CO2 Emission, System Dynamics, Policy Analysis

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Corresponding author: Abiodun Suleiman Momodu (abiodunmomodu8@gmail.com)

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Introduction

Across West Africa, more than 230 million people are without electricity access, translating to about 66% of the entire population. This means that making access available represents a life-or-death issue for the sub-region; it is estimated on a yearly basis that 3.5 million people die from indoor air pollution caused by the use of wood stoves, more than AIDS and malaria combined. This grim statistic makes it imperative to transform the economy at more than the business-as-usual rate. No doubt West Africa has the lowest human development indices, meaning that the sub-region (West Africa) needs to undergo rapid transformation, particularly in the attempt to make adequate provision of needed infrastructure such as energy, including electricity for socio-economic development. Development is energy driven, meaning that energy use drives economic growth and in turn, economic growth drives energy use. The West African sub-region is blessed with vast energy resources, though distribution is skewed towards some of countries, namely Nigeria, Ghana and Cote d’Ivoire. These vast resources notwithstanding, electricity access has remained meagre: urban areas at less than 50% and rural areas at less than 20%.

In response to these glaring challenges, the sub-regional organization, Economic Community of West Africa (ECOWAS) agreed to reposition the power sector in order to achieve universal access for the sub-region in line with global practices. Thus in 2000, the West African Power Pool (WAPP) was established to harness all the available energy resources for electricity supply system for the sub-region. Other sub-regional organisations related to electricity system development are ECOWAS Regional Electricity Regulatory Authority (ERERA), established in January 2008, and ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), established in 2010. Ever since putting these three related organisations into operations, the issues involved in electricity development has been a front runner for the sub-region. There are, however, salient issues that could affect the success and impact the aims and objectives of the sub-regional organizations established to make electricity available to all. One of these is the constraint imposed from global CO₂ emission reduction policies, on which this study aims to provide a preliminary assessment. The study’s objectives are to: examine the West Africa electric power sector under a range of technological, economic, and policy-related uncertainties; and assess what effect global policies on CO₂ emission reduction have on electricity production in the sub-region.

Significance of this study

African countries are arguably faced with the two greatest developmental barriers, namely climate change and energy access. In West Africa, Nigeria has the largest energy and population resources and energy related activities are estimated to account for about 55% of total national greenhouse gas (GHG) emissions. Curbing these activities through low-carbon development for climate change mitigation and adaptation to increase energy access, requires being done in a manner to avoid ‘choking’ developmental efforts. When it comes to climate change and GHG emissions, the usual question about energy-environment nexus is “At what cost must we grow?”. However, for countries that are energy deprived, the converse may hold, which is “At what cost must we not grow?”. In viewing policy implications to global climate change as relates to energy deprived countries, such as in West Africa, it is important to examine the approaches to policy formulation/analysis, namely, top-down versus bottom-up. This in turn will be used to examine investment decision versus pricing regime and electricity system value chain (upstream versus downstream). This study attempts to review these approaches as they relate to the electricity system in West Africa, after providing an overview of the current state of the West African electricity system.

Electricity and development globally

Without a doubt, electricity is a very relevant catalyst to affecting economic development and growth, as has been experienced in many developed countries of the world. As an example, access to electricity in the United States (US) affects the quality of life significantly, with a wide range of effect on citizens’ welfare. This example shows that the world benefits immensely from electricity. However, policies related to effectively managing CO₂ has increased cost of electricity production and transmission. With increased prices, very large segments of the society could be denied access to electricity despite projected growth in demand. This becomes critical as higher prices means less usage, which can impact negatively in poorer nations like those in the West African sub-region.

Yearly, the UN performs development ranking of nations based on United Nations Human Development Index (HDI), which was developed in 1990. The HDI, a summary composite index that is measured on a scale of 0 to 1, shows a nation’s average achievements in three basic dimensions of human development: health, knowledge and standard of living. Health is measured by life expectancy at birth; knowledge is measured by a combination of the adult literacy rate and the combined primary, secondary, and tertiary gross enrolment ratio; and standard of Living is measured by Gross Domestic Product (GDP) per capita (PPP US$). In all these indices, West African countries are ranked way below average, meaning that the sub-region is slow in development. Related to global poverty, it was estimated that there are about 3 billion persons that live on less than $2/day with about 1.5 billion having no access to electricity. In 2012, it was estimated that about 212 million or 66% of persons living in the West African sub-region have no access to electricity, representing almost 15% of the global figure. In addition, of the 2.3 billion estimated to be living on less than US$2 per day, about 10% are resident in West Africa.

Energy and development are “pull and push” in their directions as related to climate change. This is because, whereas energy is needed for development, its consumption also emits noxious CO₂ to the atmosphere. When energy use is analysed vis-a-vis environmental implications, the focus is usually narrowed down to only the potential for climate change impact. However, it is also imperative to view energy use in the context of why CO₂ is emitted (see also 6). Though CO₂ is the inevitable by-product of combusting fossil fuels to generate electricity, its benefits need to be mentioned at such time when climate change impact
is driving global policy discourse. It is important to recognize that generation and access to electricity from fossil fuels also brings about significant benefits for the health and welfare of billions across the globe. Indeed, societal electrification is identified by the National Academy of Engineering as the “most significant engineering achievement” of the 20th century[10].

This notwithstanding, energy deprived countries are at “variance” with current global energy policies as relates to climate change. This is because these proposed policies run counter to the long-established relationship of access to power as fundamental to a higher standard of living and directly related to socioeconomic development. This policy dilemma is best described by Franklin Cudjoe, Director of the Imani (Hope) Center for Policy and Education in Ghana[4], Cudjoe opines that enforcing 30% reduction in GHG emissions by U.S. Overseas Private Investment Corporation and other U.S. international aid agencies associated with their projects over the next 10 years, will undermine development in such electricity-deprived regions as Africa; i.e. the fact that Africans cannot have electricity and economic development—except what can be generated with wind turbines or solar panels—is misguided. Hence, this study presents the energy situation in West Africa below and the implication of global CO2 policies on the development of its electricity system.

West Africa, its electricity (energy) system and some socio-economic indicators

West Africa had an estimated population of 322 million in 2012 and is ranked to have one of the highest growth rates in the world at between 3.81% and 2.7% per annum[11]. Of the 14 countries associated with the sub-region, 52% is accounted for from Nigeria of the total population, covering a surface area of only 18% of the estimated size of about 5,105 million km². The Member States of West Africa Community are energy deprived countries. Only three countries in the sub-region, namely Ghana, Guinea Bissau and Nigeria, have access (in whatever definition) to electricity that is above 50%. Liberia has the lowest access level at 4.1%. The total electricity generating capacity of the sub-region is <20 GW (which represents only about 45% of South African electricity generating capacity), giving it an average per capita power capacity of 0.05 kW/person. In energy terms, the average per capita electricity consumption is 114 kWh/person[12]. However, production and consumption levels are highly skewed towards a few countries in the sub-region. It is held that for a country to be electricity sufficient, it must have an average per capita consumption of 500 kWh/person, while for industrialization it must be up to an average of 1000 kWh/person[13]. The highest per capita electricity consuming country in the West African sub-region is Ghana at about 266 kWh/person, a far cry from that needed to provide basic access, and a very far cry from that that can lead to transformation. Table 1 shows the electricity supply structure in the sub-region as reported by the WAPP. The table also shows the proportion contributed by each of the countries in the WAPP. Table 2 and Table 3 present electricity and economic indicators, respectively, of each of the country in WAPP. Table 2 details the electricity demand growth, key generation fuels, installed power capacity and access to electricity by the population. Table 3 shows socio-demographic and economic indicators of the countries. Cape Verde was not considered as it is not part of the WAPP.

### Table 1. WAPP electricity supply structure in 2015.

| Country          | Generation and transmission company, and distribution                                                                 | Electricity production (million kWh)[3] | Power capacity (MW) | % contribution to WAPP capacity |
|------------------|----------------------------------------------------------------------------------------------------------------------|----------------------------------------|---------------------|---------------------------------|
| Benin            | Société Béninoise d’Énergie Electrique and Communauté Electrique du Bénin                                            | 124                                    | 48                  | 0.3                             |
| Burkina Faso     | Société Nationale d’électricité du Burkina Faso                                                                        | 611.6                                  | 228                 | 1.4                             |
| Côte d’Ivoire    | Société de Gestion du Patrimoine du Secteur de l’Électricité (SOGPE)                                                    | 5,275                                  | 1,313               | 8.0                             |
| The Gambia       | National Water and Electricity Company (NAWEC)                                                                           | 160                                    | 144                 | 0.9                             |
| Ghana            | Volta River Authority and Electricity Company of Ghana                                                                     | 6,746                                  | 2,837               | 13.3                            |
| Guinea           | Electricité de Guinée                                                                                                   | 850                                    | 419                 | 2.5                             |
| Guinea Bissau    | Electricidade e Aguas da Guine-Bissau                                                                                 | 65                                     | 21                  | 0.1                             |
| Liberia          | Liberian Electricity Corporation                                                                                       | 350                                    | 22.6                | 0.1                             |
| Mali             | Energie du Mali                                                                                                         | 515                                    | 240                 | 1.5                             |
| Niger            | Société Nigerienne d’Electricité (NIGELEC)                                                                             | 404.6                                  | 0.121               |                                 |
| Nigeria          | Various entities                                                                                                       | 21,920                                 | 10,459              | 63.5                            |
| Senegal          | Société d’Électricité du Sénégal                                                                                      | 1,880                                  | 768                 | 4.7                             |
| Sierra Leone     | National Power Authority (Sierra Leone)                                                                               | 80                                     | 362                 | 2.2                             |
| Togo             | Togo Electricité et Communauté Électrique du Bénin                                                                     | 0                                      | 181                 | 1.1                             |
| Total            |                                                                                                                       | 38,826.6                               | 16,476.221          | 100.0                           |

Sources: 14
Table 2. Member states of WAPP electricity indicators in 2015.

| Member state | Electricity demand growth (% p.a.) | Key generation fuels | Installed power capacity (MW) | Access to electricity (% of population) |
|--------------|-----------------------------------|----------------------|-------------------------------|----------------------------------------|
| Benin        | 5.3                               | Oil                  | 48                            | 25                                     |
| Burkina Faso | 9.0                               | Oil, Hydro           | 228                           | 15                                     |
| Côte d’Ivoire| 6.0                               | Gas, Hydro           | 1,313                         | 47                                     |
| The Gambia   | 9.0                               | Oil, Gas             | 144                           | 31                                     |
| Ghana        | 9.6                               | Hydro, Gas, Oil      | 2,837                         | 60                                     |
| Guinea       | 1.8                               | Oil, Hydro           | 419                           | 23                                     |
| Guinea Bissau| -9.9                              | Oil                  | 21                            | 57                                     |
| Liberia      | 0.0                               |                      |                               |                                        |
| Mali         | 0.5                               | Hydro, Oil           | 240                           | 18                                     |
| Niger        |                                   |                      |                               |                                        |
| Nigeria      | 8.0                               | Gas, Hydro, Oil      | 10,459                        | 51                                     |
| Senegal      | 4.3                               | Oil, Hydro           | 768                           | 42                                     |
| Sierra Leone | 3.9                               | Oil, Hydro           | 362                           | 12                                     |
| Togo         | 6.6                               | Oil, Hydro           | 181                           | 20                                     |
| West Africa  | 4.3                               |                      |                               | 16,458.6                               |

Sources: 15–18

Table 3. Member states of WAPP development indicators in 2017.

| Member state | GDP 2017 (billions of US$) | GDP growth rate 2017 (% p.a.) | Per capita income (US$/Cap) | Population | Size (KM²) | Density (persons/KM) |
|--------------|-----------------------------|-------------------------------|-----------------------------|------------|------------|----------------------|
| Benin        | 9.3                         | 5.6                           | 829.8                       | 11,175,692 | 112,622    | 99                   |
| Burkina Faso | 12.9                        | 6.7                           | 670.7                       | 19,193,382 | 273,800    | 70                   |
| Côte d’Ivoire| 40.4                        | 7.8                           | 1,662.4                     | 24,294,750 | 318,000    | 76                   |
| Gambia, The  | 1.01                        | 3.5                           | 483                         | 2,100,568  | 10,000     | 208                  |
| Ghana        | 47.3                        | 8.5                           | 1,641.5                     | 28,833,629 | 239,460    | 127                  |
| Guinea       | 10.5                        | 8.2                           | 825.3                       | 12,717,176 | 245,857    | 52                   |
| Guinea Bissau| 1.34                        | 5.9                           | 723.7                       | 1,861,283  | 36,120     | 66                   |
| Liberia      | 2.2                         | 2.5                           | 456.1                       | 4,731,906  | 96,300     | 45                   |
| Mali         | 15.3                        | 5.3                           | 338.5                       | 18,541,980 | 1,240,192  | 15                   |
| Niger        | 8.1                         | 4.9                           | 378.1                       | 21,477,348 | 1,266,700  | 17                   |
| Nigeria      | 375.8                       | 0.8                           | 1,968.6                     | 190,886,311| 923,768    | 210                  |
| Senegal      | 16.4                        | 6.8                           | 1,033.1                     | 15,850,567 | 192,000    | 82                   |
| Sierra Leone | 3.8                         | 4.2                           | 499.4                       | 7,557,212  | 71,620     | 105                  |
| Togo         | 4.8                         | 5.6                           | 617.2                       | 7,797,694  | 54,385     | 143                  |
| West Africa  | 549.15                      | 5.45                          | 866.2                       | 367,019,498| 5,084,857  | 82.96                |

Sources: 19–21
Realizing this level of deficiency in the sub-region, ECOWAS, which was set about 40 years ago in 1975, established and institutional framework in form of WAPP, ECOWAS Regional Electricity Regulatory Authority (ERERA) and ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), needed to harness the potentials in the energy resources of the sub-region for the benefits of the people. Energy is critical to all the economic growth desired in the sub-region and will be needed for infrastructure development such as roads, water, and housing amongst others.

Methods
Due to the decisions that must be made to assist in decision making requires facts to be gathered for analysis, and how these facts are gathered and analysed will determine the outcome of decisions that will be made. This study briefly looks at the approaches to acquiring facts and data analysis that leads to decision making, vis-a-vis, the West Africa electricity system and global CO₂ reduction policies. The study uses two techniques applied in information processing and knowledge ordering or style of thinking and teaching (application of policies). These techniques are: top-down versus bottom-up as they relate to global CO₂ policy and electricity system development. The approach was then applied to analyse investment decision versus pricing regime, as well as looking at the electricity value chain from the upstream versus downstream points of view. Data were drawn from secondary sources on energy utilization in the West African sub-region.

Top-down and bottom-up strategies
Top-down and bottom-up are two techniques that both represent strategies of information processing and knowledge ordering. Laws are made in democratic legal system in two ways: adjudicating (bottom-up) or legislating (top-down). In adjudicating, which is bottom-up, laws are abstracted from the decisions made in individual cases. On the other hand, in legislating, general principles are declared through a centralized authority to be applied in individual cases. These two processes are noted to have their merits and demerits and they appear in a variety of fields. Both in practice can be seen to represent thinking and teaching styles. In legislative deliberation, the system is broken down to gain insight into its compositional sub-systems, while its adjudicative partner piece together the systems in a way that produces more complex systems. These approaches are operated in multilateral state organizations involved in international policy formulation.

Three broad strategies for consideration are carbon tax, cap and trade and regulator approach (The Center on Budget and Policy Priorities (2015)). These instruments have been considered to be relevant to limiting carbon dioxide (CO₂) and other greenhouse gas emissions into the atmosphere. Market-driven strategies such as carbon tax and cap and trade are measures have top-down strategies when viewed from the perspective of a region that has poor resources and little or no technical knowledge to respond to climate change impact adequately. West Africa falls into such region. These thoughts are better explained in Mendelsohn, Dinar and Williams (2006) and O’Brien and Leichenko (2000). As noted by O’Brien and Leichenko (2000), vulnerable regions in the world such as countries in West Africa are subjected to as regards climate change and globalization. Laukkonen et al. (2009) calls for a methodology and comparison tool to assess the most cost-effective and appropriate strategies for each community. Laukkonen et al. (2009) opined that “strategies need to be evaluated to allow successes to be translated into local contexts and communalized with the involvement of local authorities using participatory approaches. The overall goal is community development through local government leadership, comprehensive planning and prioritization”. The latter is in form of regulatory approach and is a “bottom-up” strategy, which is what West Africa region, the most vulnerable to the impact of climate change, would need to address her challenges in terms of climate change and globalization.

Data sources
Data were gathered from different sources related to countries being studied including those from multilateral organizations for assessment. For WAPP member country level data, the study relied principally on information gleaned from websites of WAPP and ECOWAS Regional Electricity Regulatory Authority (ERERA) and WAPP publications. Other sources include those from the World Bank, United Nations organs and agencies, some of the Central Banks of ECOWAS Member States, the Central Bank of Côte d’Ivoire (https://centralbank.monnaie.me/Central-Bank-of-Cote-d’Ivoire.htm), some of the Bureaus of Statistics (https://www.nigerianstat.gov.ng/), http://www.statsghana.gov.gh/, http://www.gbos.gov.gm/, some member country electricity regulatory bodies amongst other (http://www.purc.com.gh/, http://www.nercng.org/). The data sourced are those on population, average growth rate, gross domestic product (GDP), per capita income, average per capita electricity demand, electricity generated, generation technology type, density, land size, amongst others from various journal articles, publications from international organizations and internet sources (such as World Bank, Central Banks of ECOWAS Member State Countries; National Bureau of Statistics; Electricity Regulatory Bodies). WAPP member country level data elicited from WAPP and ECOWAS Regional Electricity Regulatory Authority (ERERA) serves as the set of basic data used to develop and run the main model (see Figure 3). Other data elicited from various journal articles and internet sources (such as Central Banks of ECOWAS Member State Countries; Bureau of Statistics; Electricity Regulatory Bodies) include population and its average growth rate, GDP, per capita income, average per capita electricity demand, electricity generated, average electricity tariff, generation technology type, amongst others. The generated SD model examines the (nonlinear) relationship regarding generation adequacy and GHG emission reduction in the WAPP. It evaluated the strain of providing adequate supply capacity against emission reduction from generation technologies in the West African electricity system. The complexities in the West African electricity system were arranged in the model to establish the basic interconnecting structure for the system analysis; this is to achieve global expectations of emission reduction and economic growth.
Systems dynamics

The SD model was developed using Vensim DSS version 6.2. SD is a principle that is developed using computer-aided software to understand how changes occur in a system over time. The principle is useful for policy analysis and design to understand physical, biological, and social systems from the perspective of information feedback and mutual or recursive causality. Areas of usefulness of the field of SD include planning and policy design, public management and policy, biological and medical modelling, energy and the environment, theory development in the natural and social sciences, dynamics decision making and complex nonlinear dynamics. The structure of a system informs its behaviour, and this structure consists of feedback loops, stocks and flows, and nonlinearities created by the interaction of the physical and institutional structure of the system with the decision-making processes of the agents acting within it. In its structure, the model is made up of three stock/level variables, 5 flow rates and 5 auxiliary variables with 8 parameters. Stocks are accumulations, which characterizes the state of the system and generate the information upon which decisions and actions are based. Stocks give systems inertia and provide them with memory. Stocks create delays by accumulating the difference between the inflow to a process and its outflow. By decoupling rates of flow, stocks are the source of disequilibrium dynamics in systems. In this system, the stocks include the capacity under construction, generation capacity and the population being serviced by the electricity system. The inflows and outflows are initiating capacity, completion, scrapping and net population growth rate. An inflow at a point in time may serve as outflow at another point of the stock. For example, completion is an outflow from capacity under construction and at the same time an inflow into generation capacity. The running of the developed model after establishing the structure in a steady state is dependent on the parameters. It is from these parameters that the leverage point in the model was determined. The model parameters, showing base case values together with two other possible policy scenarios, namely unimproved and improved case values respectively, are listed in Table 4.

However, before examining the results of the system behavior, the basic modes of dynamic relationship between structure and behavior is explained. The basic modes explain the dynamics in the relationship between structure and behavior in a dynamic model, identified along with the feedback structures generating them. These modes include growth, created by positive feedback; goal seeking, created by negative feedback; and oscillations (including damped oscillations, limit cycles, and chaos), created by negative feedback with time delays. More complex modes such as S-shaped growth, overshoot and collapse arise from the nonlinear interaction of these basic structures. In order to describe the model output, it is important to look at the reference mode. The reference mode represents the historical behavior of some variables in the model. These basically display exponential growth structure (Figure 1).

Analysis and discussion

This section presents electricity consumption pattern in West African countries and global CO₂ reduction policies and instruments in use. In addition, a SD assessment of the electricity system in the sub-region is also provided.

Global CO₂ reduction policies and instruments

After the Earth Summit held in Rio de Janeiro in 1992, the world has been making concerted efforts at reducing CO₂ (GHG) emissions to the atmosphere. Many policies and instruments have been developed to tackle the menace. Table 5 gives a summary and comparison of some of the types of international instruments that have been developed to support low emission planning. There are several stages to low emission planning processes, characterized by a substantial degree of complexity and cost. The intervention policies from 2007 in Bali to the recent effort coming up in December 2015 are shown in Figure 2.

1This refers to any formerly executed written document that formally expresses a legally enforceable act, process, or contractual duty, obligation, or right, and therefore evidences that act, process, or agreement for operating the electricity city in any of the West African countries.

Table 4. Parameters in the systems dynamic model and policy uncertainties.

| Parameter                              | Unimproved case value | Base case value | Improved case value |
|----------------------------------------|-----------------------|-----------------|---------------------|
| Birth rate                             | 0.027                 | 0.027           |                     |
| Emission factor electricity (tCO₂/MW)  | 0.90                  | 0.60            | 0.40                |
| Time to adjust capacity (Years)        | 25                    | 12.5 years      | 10                  |
| Construction time (Years)              | 5 years               | 5 years         | 5                   |
| Capacity life time (Years)             | 25 years              | 25 years        |                     |
| Hours in the year (Hours)              | 24 *300               | 24 *300         | 24*300              |
| Capacity factor (Fraction)             | 0.85                  | 0.85            | 0.85                |
| Normal per capita electricity demand (kWh/Person) | 112                   | 146             | 2200                |
### Table 5. Different regimes of international response to climate change.

| Policy                                      | Instrument          | Background                                                                 |
|---------------------------------------------|---------------------|-----------------------------------------------------------------------------|
| Technology Needs Assessment                 | TNAs                | • TNAs are an approved element of United Nations Framework Convention on Climate Change (UNFCCC) technology transfer framework under Article 4.5.  
• The Global Environment Facility (GEF) has provided TNA support to more than 90 countries and has initiated support for more in-depth TNAs to about 30 countries. |
| Bali Action Plan                            | NAMAs               | • NAMAs were adopted under the Bali Action Plan as a mechanism for developing countries to undertake voluntary projects to reduce GHG emissions with international support.  
• The Copenhagen Accord notes that countries should describe NAMAs in their national communications and establishes registry of NAMA projects proposed for international support.  
• The COP 16 draft decision notes that NAMAs should “include information on mitigation actions, the national greenhouse gas inventory report, including a description, analysis of the impacts and associated methodologies and assumptions, progress in implementation and information on domestic measurement, reporting and verification and support received…” |
| Copenhagen Accord                           | LEDS/Low-Carbon Development Strategies (LCDS) | • As first noted in the Copenhagen Accord, the COP 16 draft decision states that “a low-carbon development strategy is indispensable to sustainable development” and encourages developing countries to prepare low-carbon development strategies.  
• Pilot projects to assist countries with LEDS development have been initiated by the United States, Netherlands, European Commission, and others. |
| Roadmaps                                    |                     | • A technology roadmap is a specialized type of strategic plan that outlines activities an organization can undertake over specific time frames to achieve stated goals and outcomes. Technology-specific roadmaps are intended to support the development of specific types of technologies. The roadmaps serve to achieve consensus on low-carbon energy milestones, priorities for technology development, policy and regulatory frameworks, investment needs, and public engagement. |

Source: adapted from 36

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**System dynamics model**

SD (model in Figure 3) examined the interconnections and quantified the electricity system in West Africa. The results are discussed next.

**Behaviour of system dynamics model for the West African electricity system**

System dynamics, policy analysis, and design are used for learning and decision making. Interconnections in a system are captured in an SD model to define the structure of the system. The

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2Draft decision -/CP.16.Outcome of the work of the Ad Hoc Working Group on long-term Cooperative Action under the Convention. #64. Pg. 10. http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf

3Draft decision -/CP.16.Outcome of the work of the Ad Hoc Working Group on long-term Cooperative Action under the Convention. #6. Pg. 2. http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf

4Draft decision -/CP.16.Outcome of the work of the Ad Hoc Working Group on long-term Cooperative Action under the Convention. #65. Pg. 10. http://unfccc.int/files/meetings/cop_16/application/pdf/cop16_lca.pdf d Text from Antonia Gawel, IEA
Figure 2. Timeline of international response to climate change and key decisions towards a global agreement: 2005 to 2018.

Figure 3. System dynamics representation of added capacity to power generation in West Africa and its effect of CO₂ Emission adapted from 37.
structure arises from the system behaviour. Behaviour explains the dynamics and forces underlying the complexity and change in any system. Feedback loops, stocks and flows, and nonlinearities make up system structure, created by the interaction between the interconnections, namely the physical and institutional structure in the system, have decision-making processes of the agents acting within it. In the SD model, there are basic modes of dynamic relationship between structure and behaviour, representing the feedback in the system.

Estimated energy needs of the West African electricity system to provide universal access

The SD model in Figure 3 identified a number of variables in the West Africa electricity system. This study reports the future capacity addition in the system needed to meet electricity consumption, as well as emission emanating from the electricity generated in the system. The parameter most significant in the model in affecting ‘capacity under construction’ is the ‘time to adjust capacity’ that affects generation capacity. Generation capacity in turn is what determines energy generated, which in turn affects power demand and CO₂ emissions. The result from the model run shows an inverse relationship, namely at lower time space of ‘time to adjust capacity’ the higher the capacity addition that could be achieved and vice versa. The inference simply means that the longer it takes to adjust capacity, the less capacity addition to meet demand. In terms of emission, this is desirable but will thus have a ‘choking’ effect on the economy as per capita demand is reduced suppressing consumption. In order to drive growth with reduced emission, the ‘time to adjust capacity’ was reduced with improved technology in terms of the generation technologies deployed to have reduced emission factor (Improved Value), as the driving parameter in terms of emission is the emission factor, which in other words is due to technology improvement in generation plants.

Table 6 and Figure 4 and Figure 5 display results for generation capacity and emission from the electricity generated in the West Africa electricity system under three plausible policy scenarios, namely, Base, Improved and Un-Improved. The Base case simply looks at the system as it is historically and is examined in the context of no change in policy direction and also was used to form a reference case. The other two policy options are Improved and Un-Improved cases. In the Improved Case it was assumed that the time to adjust and emission factor were deliberately altered to meet the policy of providing 2.2 MWh/Person/Year power demand. For the Un-Improved Case, it was assumed that the system will degenerate from its Base Case values due to neglect orchestrated by unfavourable response to global policy on CO₂ reduction. However, the curves for each Cases in the analysis shows exponential growth with Improved Case showing faster growth rate than others.

Policy analysis: CO₂ emission reduction versus electricity system development in West Africa

Without doubt, modern energy supply has been shown severally to be sine qua non to economic development. This

Table 6. Generation capacity and emission from generated electricity, 2011 to 2060.

| Year | 2011 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 |
|------|------|------|------|------|------|------|------|------|------|------|------|
| Gen. Cap. (GW) | 16.48 | 17.32 | 20.17 | 23.99 | 28.63 | 34.20 | 40.86 | 48.81 | 58.31 | 69.66 | 83.22 |
| Emission (MtCO₂) | 68.30 | 71.80 | 83.60 | 99.50 | 119.00 | 142.00 | 169.00 | 202.00 | 242.00 | 289.00 | 345.00 |

Figure 4. Generation capacity under three policy scenarios: Base, Improved and Un-Improved (MW).
The challenge has been identified as needing international attention, with focus on a combined agenda of poverty eradication and sustainable development, in the context of climate change. The recent launching of the UN Sustainable Energy for All initiative (SE4All), expresses this priority primarily. Still, further attention would need to be given to areas of such tension and conflict within such an agenda as concerns climate change.

The approaches (either top-down or bottom-up) to making such medium- to long-term decisions are important to their success. This study looks at current policies as a constraint to expanding energy access in West Africa. This will invariably affect the electricity system of the sub-region. It will be interesting to know if they were developed as top-down or bottom-up policies to affect energy access.

For example, relating to energy access, international policy makers presume that roughly 2-3 billion people who presently lack modern energy services will only demand or consume them in small amounts over the next several decades. This is because a faulty concept of “energy access” informs top-down decision making on energy issues. This is often defined in terms that are unacceptably modest, which in turn has compounded the difficulty of decision-making in such a complex space. This implies projections of future energy consumption that are potentially far too low and inevitably leave, albeit unintentionally, billions deeply impoverished. Such approaches risks becoming self-fulfilling, and subsequently, affect the view decision makers have about the kind and scale of challenges confronting the people. Analysts and policy makers would be considering to be appropriate as influenced by policies, technologies, levels of investment and investment vehicles.

Policy analysis is important to evaluate its formulation and assess the success of the policy. There was a global shift in the electricity sector management policy in the last two and a half decades towards liberalized markets. This shift created a higher degree of uncertainties in systems that are more stable than those in the electricity system in West Africa that was run as a state-owned enterprise before now. Thus, the West African economy, and invariably the electricity system shows as being more vulnerable to international policies than before. Presently, West Africa has about 17% of the poorest 75% of the world population using only about 10% of global energy, representing continuous deep global inequity.

Figure 5. Emissions from West Africa electricity system generation under three policy scenarios: Base, Improved and Un-Improved (tCO₂).

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5see Goldratt and Cox (2004) and Goldratt (1997) for theory of constraint

6Defined as those living on less than US$2/day.
critical role. Having a better understanding of the significance of electricity system to improving the HDI requires a better understanding of energy access. A better understanding of the scale of energy access challenge in West Africa using electricity as benchmark, would require the knowledge of how much energy is actually needed to enable poverty alleviation, a level termed “modern energy access”. This approach will give a bottom-up approach to decision making in the policy formulation to answer this question. It is however acknowledged that providing modern energy access is not simplistic. Figure 1 in 39 presents a wide range of what can be meant by “energy access”46. The figure shows how on the average, it differs, both between countries at “full electrification” as well as those at much lower access rates. This considerable average spread of annual household consumption and access levels complicates comparison.

To make the point for electricity system development, it is necessary to compare access and consumption of the West African sub-region. The comparison is made between places having modern energy access by any definition of the term, with essentially 100% of residents and the broader economy under full electrification. The average resident of the United States consumes about 13,400 kWh per year, with a large variation by state. In comparison, Europeans generally consumes less energy on the average than Americans. As shown in Table 7, energy consumption in Germany for the average resident is 7,200 kWh per year, Sweden about 15,000 kWh and Greeks about 5,200 kWh, with Bulgaria being at the end of the rung at about 4,500 kWh, or about 60% of German and a third of US levels. The global average in 2010 was just under 3,000 kWh per capita per year, barely 75% of Bulgarian consumption, with these figures of energy consumption skewed heavily towards the industrialized nations as against the large number of people with no access at all. Coming to the West African sub-region, the highest per capita electricity consumption is 550 kWh for Cabo Verde. Assuming this is for 5-person household, this translates to only 50 kWh/Cap in a year. As mentioned earlier, a far cry from what is needed to move from poverty level to transformation desired for its economy or put another way “shining light on poverty in energy deprived countries” [see 39].

Energy access vs energy consumption
The first and most pronounced argument on eliminating energy poverty is that of providing energy access and not the amount consumed. To make any meaningful change, these two must be viewed together. Access without the desired quantity is as good as not having it. To understand this better, values for the US, Germany and Bulgaria compares well with the definitions of energy access that typically provide the basis for policy discussions and analyses. Taking “initial threshold” for energy access as defined by the International Energy Agency as 250 kWh per year for rural households and 500 kWh per year for urban households, with a 5-person household44,45). This will be roughly 50–100 kWh/year per person, or about 0.5% of that consumed by the average American or Swede, and 1.7% of the average Bulgarian. Illustrating this in Figure 5 shows stark differences of various thresholds of per capita energy access. To put the analyses more in perspective, the use of a single 100-Watt light bulb five hours per day equates to about 73 kWh over the course of a year (i.e., 40 W * 5hr * 365 days). Furthermore, it is interesting to note that 2010 levels for the US, Germany and Bulgaria, are projected for 2035, represented by the top three bars to represent global per capita energy access [see 39]. Figure 2 in 39 also included projections of the US Energy Information Agency for 2035 as well as the actual 2010 per capita levels of 2010 based on World Bank assessment. The bottom bar of the graph is the IEA definition of “energy access,” which is obviously small in comparison to the other five bars, despite assuming in its analysis, a demand of 750 kWh/year per capita by 2030 for new electricity connections.

Achieving energy access is a multi-level process.39,50,51. For instance, IEA noted that “Once initial connection to electricity has been achieved, the level of consumption is assumed to rise gradually over time, attaining the average regional consumption level after five years” [see 35]. Including initial period of growing consumption reflects the fact that eradication of energy poverty is a long-term endeavour.

Presented in Table 8 is a modified World Bank scheme useful got various levels of energy access. The scheme illustrates different “tiers” of access. This is a good reflection of what access versus consumption looks like. As shown in the table, TIER 5 in the policy is the highest level of access at 2,121 kWh/year per household of five people, or roughly 420 kWh/capita/year. Comparing this tier with energy consumption in wealthy countries indicates that it is <10% of Bulgarian consumption, still much lower than what typical energy services would imply. Thus,

| Country/Region       | Energy access level (%) | Electricity consumption (kWh) |
|----------------------|-------------------------|-------------------------------|
| USA                  | 100                     | 13,400 (2010)                |
| Germany              | 100                     | 7,200 (2010)                 |
| Greece               | 100                     | 5,200 (2010)                 |
| Sweden               | 100                     | 15,000 (2010)                |
| Bulgaria             | 100                     | 4,500 (2010)                 |
| West Africa sub-region | 34                      | 146 (2012)                   |
| World                | 83                      | 3000 (2010)                  |

39,47; Author’s compilation
Table 8. Modified tiers of electricity service demand<sup>39</sup>: Use of electricity services.

| TIER 1 | TIER 2               | TIER 3               | TIER 4               | TIER 5               | TIER 6               |
|--------|----------------------|----------------------|----------------------|----------------------|----------------------|
| None   | Task lighting AND phone charging (or radio) | General lighting AND television AND Fan (if needed) | Tier 2 AND Any low-power appliances 50–150 kWh | Tier 3 AND any medium-power appliances 150 – 250 kWh | Tier 4 AND any high-power appliances 250 – 420 kWh |
| 0kWh   |                      |                      |                      |                      |                      |
| 1–20 kWh |                      |                      |                      |                      |                      |

Introducing policy for access should be understood that it does not a guarantee transformational consumption for the countries involved. At best, countries with increased access may achieve poverty management.

Figure 9 in 52 shows the historical growth in energy access for 10 countries. Energy access here is shown as “electricity access” and is defined as “household electrification” at an unspecified level of consumption. Each of the countries’ represented reached a total 100% by different periods, while some others are still not at a total 100% access. So, it is imperative that researchers investigate how fast and how far truly modern energy access occur. This is a generational challenge as it concerns accelerating transition to a radically different, and inclusive, energy system, and providing a just and consequential rationale for much greater attention to innovation in energy systems. Properly understanding the scale of the challenge is a first step in that transition. Feasible discussion of the cost of achieving such ambitious goals will then follow from knowing this scale as a necessary prerequisite of the organization of modern economies. However, it is important to recognize that any such discussion is not only laden with assumptions about economics, technologies and politics - but also that there is evidence of nations that have moved rapidly to achieve greatly increased levels of access in the context of rapid economic growth<sup>36,37</sup>.

West Africa and energy access

Minimal electricity access is a major challenge to more than one and a half billion people<sup>9</sup>. Of this figure, approximately 12.5% or 0.188 billion persons are in West Africa alone. This critical mass of people clearly presents a case for West Africa sub-region when considering global policy on CO<sub>2</sub> emission reduction in terms of policy, national plans, and projects to improve access. In addition, it is vital to realize that the policies for transformational energy access is quite different from those that underpin sustained growth in economies and consumption. Clearly an estimation of energy provision to meet modern access must recognize other sectors of the economy other than the residential sector alone in critical power planning exercises and policies. This is because energy access is woven to all economic sectors, which includes severely constrained business and industry growth due to lack of access and lack of access to high quality services, namely reliable enough to meet the needs of private sector enterprises, from hospitals to factories. Policies for transformational energy access must not aim too low, in order to reduce the risks of policy failure and improve the opportunity costs of policy success. Achieving more ambitious goals will then require more attention on real transformational change.

Conclusion and recommendations

This study examined the implication of global CO<sub>2</sub> reduction policy on electricity system in West Africa, which has numerous energy-deprived member states. Two approaches were applied in the analysis, namely policy formulation and system dynamics principle. Though a more rigorous analysis would still need to be conducted on the system, from the policy formulation perspective, the current study posits that when policies are formulated with no grassroots or stakeholders’ input, it is likely to impose constraints on those who are to implement it. It is agreed that there is need to reduce GHG, particularly CO<sub>2</sub> emission into the atmosphere, but the approach to its implementation differs. Policy is seen to be central to implementation as it can cause a ‘gagging’ and ‘chooking’ effect on the development aspirations of energy deprived countries like those in West Africa, if it does so without needed consideration. Also drawing from 31 and 29, based on the system dynamics model, it was identified that ‘time to adjust capacity’ is very significant to increasing capacity and achieve reduced GHG emissions. The countries will need to look at more efficient generation technologies with reduced emission factors compared to what is currently in use by the West African electricity system. The study also brought out the fact that energy access is necessary to engage more persons in the grid, but there is the need for decision-makers to also consider consumption level in order to avoid the trap of ‘poverty maintenance’ rather than ‘transformational change’.

Recommendations from the results indicate that:

1. WAPP could reduce time to adjust capacity for the stakeholders in the generation sector to achieve increased generation capacity quickly.
2. It is important that decision-makers not only beat the drum for energy access, but also to argue the case for increased consumption.
3. As a fallout from the second recommendation, it becomes imperative that decision-makers consider what would be the level of energy consumption that will bring about transformation rather than just achieving access.
4. The study aggregated the West African electricity system; there is the need to examine a disaggregated system to draw out important lessons for individual countries within.
the electricity system in West Africa. This will include examining different technology mix at different emission levels to address the ‘push-pull effect’ or ‘tension’ between the global reduction policy of CO₂ emission and provision of electricity for economic development to energy deprived member states.

Data availability

Underlying data

Open Science Framework: Model Documentation for Global CO₂ emission reduction policies and West African electricity system.docx, https://doi.org/10.17605/OSF.IO/WFA4514.

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Universal).

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Samuel Asumadu-Sarkodie  
Sustainable Environment and Energy System, Middle East Technical University, Guzelyurt, Turkey

- The study presented is interesting in the case of West Africa, however, the work clearly lacks novelty. There are several studies in the scope of this study, as such, well-detailed literature is expected.

- How does the present study contribute to achieving the 2030 global goals outlined in the UN-SDG?

- The structure of the study appears to be more of a review than a research paper - I suggest the authors present a concise but scientifically sound manuscript.

- The methods and analysis provided are sufficient details to allow replication by others. The model estimation method is missing.

- What is the theoretical framework that underpins the method and outcome of SD?

- Justify the importance of SD over econometric models.

- Justification for the variable selection and length of data are essential.

- How was the model validated for stability and biases that may affect statistical inferences?

- Why was West Africa selected? Is there a common factor that makes the outcome applicable to other sub-regions?

- What are the limitations of the study?

- The results need expansion — the head and tail of the discussions are difficult to assimilate.

- Proofread the manuscript for syntax and grammatical errors.
Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
No

Are the conclusions drawn adequately supported by the results?
Partly

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Climate Change Research, Environmental and Energy Economics, and Renewable Energy Technologies.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.