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Sustainable development of the West African Power Pool: Increasing solar energy integration and regional electricity trade

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ABSTRACT

The West African region is currently experiencing the challenge of meeting rapidly the growing electricity demand which has played a critical role in the low economic development rate of the region. To tackle these challenges, the West African Power Pool was established to build regional power plants and interconnected transmission infrastructures between the countries. In this study, we develop a multi-region economic dispatch model with hourly simulations to evaluate the impact of increased integration of solar PV on the interconnected West Africa electricity network. Our results show the high integration of solar PV plants reduces the supply-demand gap and load shedding in the region. All countries in the region potentially benefit from avoided generation cost and decrease in unserved electricity demand. Our study presents a sustainable strategy to diversify from hydro and gas regional projects and invest in solar PV in order to improve electricity supply and reduce the high electricity prices in the region.

Introduction

In 2016, with a population of 327 million people and a maximum available generating capacity of 12GW, 14[1] out of 15 countries in the West Africa region had an estimated 25.6GW peak demand (WAPP-Information and Coordination Centre, 2016). This illustrates the current huge gap between electricity supply and demand in West Africa and is reflected in the frequent electricity outages and load shedding experienced in each country. These outages have resulted in increased usage of diesel or petrol backup generators in domestic and industry sectors. This challenge has played a critical role in the low economic development rate of the region, as countries have not been capable of providing electricity for industrial activities (Castellano, Kendall, Nikomarov, & Swemmer, 2015). Furthermore, electricity demand in West African countries is estimated to reach two times its present level by 2030 with an average annual growth rate of 6% (International Energy Agency, 2014a). There is an urgent need for sustainable strategies to meet the rapidly growing electricity demand in West Africa.

In an effort to tackle these challenges and improve the economies of West African countries, The Economic Community of West African States (ECOWAS) established the West African Power Pool (WAPP) to develop large regional power plants, build interconnected transmission infrastructures between the countries and create a unified regional electricity market (West African Power Pool, 1999). The WAPP business plans (West African Power Pool, 2015) aims to increase regional generation capacity by 2.4 GW and interconnect these 14 countries with 6109 km of high voltage transmission lines by 2025.This current regional plan focuses on hydropower and natural gas projects, representing 74% and 23% respectively of the planned generation capacity. Hindrances to this plan are the impact of drought and climate change on hydropower plants, and vandalism on gas pipelines. In 1998, 2001, 2007 because of severe drought, Cote D'Ivoire, Ghana, and Nigeria that rely heavily on hydropower experienced significant reductions in electricity production, which in turn affected electricity trades between countries. Furthermore, climate change could potentially reduce hydropower generation by more than 50% from two main rivers in the region between 2015 and 2050 (Cervigni, Liden, Neumann, & Strzepek, 2015). Vandalism on several gas pipelines in Nigeria since 2012 has resulted in significant drop in electricity generation in both Nigeria and Ghana. However, the region has the potential to generate up to five times its 2025 projected demand from solar Photovoltaic (PV), if 1% of the estimated suitable land is utilized (Hermann, Miketa, & Fichaux, 2014). With a solar PV technical potential of 103 PWh in the region and the challenges with hydropower and gas generation, there is a need to investigate the impact of high integration of solar energy resources in meeting the rapidly growing demand of an interconnected West Africa electricity network under the operation of a single regional electricity market.

In this study, we developed a multi-region economic dispatch model with hourly simulations to evaluate the impacts of increased integration of grid connected solar PV plants to the interconnected West Africa

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[1] West African countries include Benin, Burkina Faso, Cote D'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal and Sierra Leone and Togo.

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electricity network. By developing a highly spatial and temporal model, we are able to model the varying outputs from solar PV plants installed in different locations in the region. We investigate two scenarios with different levels of solar energy integration in the year 2025. In the baseline scenario, we model a realistic condition of the system by assuming all existing and planned generation and interconnection infrastructures are operational. The renewable scenario increases solar PV integration based on the solar PV technical potential in each country. To analyse the impact of increased solar PV in the system, we compare the economic dispatch of generation units, generations costs and cross-border electricity trades from the two scenarios. This study addresses the following research questions:

1. What is the impact of high integration of solar energy sources in closing the supply-demand gap in West Africa and meeting rapidly growing demand?
2. With high integration of solar PV plants, what are the potential benefits of cross-border electricity trading in the West Africa's interconnected electricity network?

The rest of the paper is structured as follows; Section 2 presents a review on related literature and highlights the contribution of this study. Section 3 describes the model, data inputs and scenarios developed. Section 4 presents the results from the two scenarios and sensitivity analysis on demand and fuel prices. Section 5 summarizes conclusions from the simulation results and presents an overview of future research.

Related research studies

There have been a number of studies that analyse the impact of integrating high amounts of renewable energy sources on the operation of generation and transmission infrastructures in interconnected electricity networks between different countries. The type of renewable energy resources examined in literature is dependent on its economic potential in the given region or countries. For example, Van Hulle et al. (2009) investigated the impact of increasing wind capacities on the flow of electricity between several countries in Europe and concluded that upgrades to interconnections between countries and national grids is required to avoid congestion in the network. The authors in (Jaehnert, Wolfgang, Farahmand, Voller, & Huertas-Hernando, 2013) examined how large amounts electricity generated from Nordic hydro power plants can be utilized to balance the fluctuating supply from other variable renewable energy sources. Brancucci Martínez-Anido et al. (2013) showed that high integration of variable renewables sources in the European interconnected electricity network has the benefit of reducing dispatch costs from conventional power plants. Schmid and Knopf (2015) concluded that in a decarbonized scenario, the expansion of the European electricity network has the potential of reducing the total system costs up to 3.5% over a 40-year period. The authors in (Dominković et al., 2016) analysed a 100% renewable energy scenario in South East Europe and concluded that by integrating the various sectors of the energy system and utilizing heat energy storage, there was significant savings of primary energy consumption in the region. During cross border electricity exchanges, due to the limits of transmission lines between countries there are sometimes unplanned electricity flows through other neighbouring countries that have sufficient capacities in their grids. Jacottet (2012) finds that because the economic costs of such flows can be challenging to quantify, there have been no reimbursement to transmission system operators that experience these intrusions in their grid.

Several energy and power system models have been developed in modelling the integration of renewable energy sources in interconnected electricity networks. Most of these models represent a country (Brancucci Martínez-Anido et al., 2013; Collins, Deane, & Gallachóir, 2017; Spataru & Barrett, 2012; Spiecker, Vogel, & Weber, 2013; Zickfeld, Wieland, Blohmke, Sohm, & Yousef, 2012) or group of countries (Brouwer, van den Broek, Zappa, Turkenburg, & Faaij, 2016; Haller, Ludig, & Bauer, 2012) as a node in the network, with generating capacities and interconnected transmission lines aggregated by fuel type and line limit capacities respectively. However, recent studies have started increasing the spatial resolution of their models by dividing countries into subregions in order to better represent the interconnected grid and intermittent characteristics of renewable energy sources in different locations. Fürsch et al. (2013) models the ENTSOE-E countries as 224 nodes to account for load flow in the region and calculates the interconnected grid extensions required in a low carbon Europe by 2050. In examining cost efficient extensions to the entire European electricity network in 2020 following high penetration of wind and solar, the authors in (Schaber, Steinke, & Hamacher, 2012) used the URBS-EU model and split the network into 83 regions; 50 transmission network operators and 33 offshore areas. Least cost pathways for a sustainable ASEAN electricity system are presented in (Huber, Roger, & Hamacher, 2015), and a URBS-ASEAN model is used in the study to divide 11 countries in South-East Asia into 33 regions based on load centres and location of energy resources. Bogdanov and Breyer (2016) divide 5 countries in North-East Asia into 13 regions based on national boundaries and transmission grid division in China, with the aim of analysing a fully renewable and cost-effective grid in the region. While 4 countries in North-Asia are divided into 10 regions in (Otsuki, Mohd Isa, & Samuelson, 2016) based on supply facilities and electricity demand locations in order to determine the benefits and barriers of increasing renewables energy production and interconnections in the region. The model in (Eser, Singh, Chokani, & Abhari, 2016) is an exception as it does not divide the interconnected countries in Central and Western Europe, but instead models all generating power plants and high voltage transmission lines in the region. However, the model in (Eser, Singh, Chokani, & Abhari, 2016) only focuses on the impact of renewables plants on thermal power plants.

There are a few studies on modelling the interconnected electricity network in West Africa. Initial studies addressed the need for an interconnected electricity network in West Africa. The following reports (United Nations Economic Commission for Africa, 2003; World Energy Council, 2003, 2005) present the interconnection of national grids as a solution to the challenges of low access and unreliable supply of electricity in the region. An interconnection strategy was presented in (Gnansounou, 2008; Gnansounou, Bayem, Bednyagin, & Dong, 2007), where there would be more than just electricity exchange among countries but also a single electricity market for the entire region. This strategy showed a potential cost savings of 38% over a period of 20 years (Gnansounou, Bayem, Bednyagin, & Dong, 2007). Sparrow, Masters, and Bowen (2002) developed a cost optimization model that indicated up to a 20% savings in total operation cost can be achieved from interconnections in West Africa over a 10-year period. The SPLAT model developed in (Miketa & Merven, 2013) quantifies the investment costs needed to have a regional electricity mix constituting 56% renewable energy sources by 2030 as $55 billion. These aforementioned models for West Africa represent each country as a node and thus do not consider the spatial intermittency of renewable energy sources in the region.

So far to our knowledge, there is a lack of highly spatial power system model for West Africa region that considers the impact of high integration of solar energy in meeting the rapidly growing demand in the region under the operation of a single regional electricity market. Our study contributes first to literature on increasing the spatial resolution of interconnected electricity network models, and adequately representing the intermittent characteristics of solar energy resources in different locations. Secondly, our study contributes to understanding the role and benefits of grid connected solar PV plants in the WAPP.

Methodology

The West African interconnected power system model

PLEXOS Integrated Energy Modelling tool (PLEXOS, 2016) developed by Energy Exemplar is used in this study to model the West