Applied Energy xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

The impact of climate change on wind and solar resources in southern Africa

Charles Fant *, C. Adam Schlosser, Kenneth Strzepek

MIT Joint Program for the Science and Policy of Global Change, Cambridge, MA, United States

HIGHLIGHTS

- We develop a risk-based assessment of climate change impacts on wind and solar resources.
- We compare results of two GHG mitigation policies in southern Africa.
- We find a low probability of significant changes for both wind and solar.
- The effects of mitigation are also mild, although they vary regionally.

ARTICLE INFO

Article history:
Received 13 November 2014
Received in revised form 5 March 2015
Accepted 6 March 2015
Available online xxxx

Keywords:
Climate change
Wind energy
Solar energy
Southern Africa
Renewable energy

ABSTRACT

The mitigation of potential climate change while sustaining energy resources requires global attention and cooperation. Among the numerous strategies to reduce Green House Gas (GHG) emissions is to decommission carbon intensive electricity production while increase the deployment of renewable energy technologies – such as wind and solar power generation. Yet the generation capacity, availability, and intermittency of these renewable energy sources are strongly climate dependent – and may also shift due to unavoidable human-induced change. In this study, we present a method, based on previous studies, that estimates the risk of climate-change on wind and solar resource potential. The assessment combines the risk-based climate projections from the Integrated Global Systems Model (IGSM), which considers emissions and global climate sensitivity uncertainty, with more regionally detailed climate information from 8 GCMs available from the Coupled Model Intercomparison Project phase 3 (CMIP-3). Southern Africa, specifically those in the Southern African Development Countries (SADC), is used as a case study. We find a median change close to zero by 2050 in the long-term mean of both wind speed and Global Horizontal Irradiance (GHI), both used as indicators of changes in electricity production potential. Although the extreme possibilities range from about −15% to +15% change, these are associated with low probability. The most prominent effect of a modest climate mitigation policy is seen in the doubled likelihood of the mode of the distribution of wind power change. This increased likelihood is made at the expense of decreased likelihood in the large changes of the distribution, but these trade-offs with the more extreme likelihoods are not symmetric with respect to the modal change.

1. Introduction

The fundamental goal of any mitigation strategy to avoid the risk of climate change is a push towards lower Greenhouse Gas (GHG) emissions. However, the most promising energy generation sources that are essentially without emissions are typically climate dependent, which is especially the case for renewable energy resources such as wind and solar. As evidence from the Intergovernmental Panel on Climate Change [1] indicates that future climate will begin to behave less like past climates in the coming decades, modeled projections of changes in the long-term future state are attractive for national energy investments that are considering large penetration of renewable energy generation in their portfolios. Southern Africa provides an interesting case study for this analysis, specifically the Southern Africa Development Countries (SADC), which includes the Democratic Republic of Congo, Tanzania, and all countries south of these two. Energy demand in this region of the world is rising quickly, with more than 12% in Mozambique and more than 10% in Zimbabwe, as observed in the last couple of years, for example [2].

* Corresponding author.
E-mail address: chasfant@mit.edu (C. Fant).

http://dx.doi.org/10.1016/j.apenergy.2015.03.042
0306-2619/© 2015 The Authors. Published by Elsevier Ltd.

Of the countries in this region, South Africa has shown the most interest in wind and solar technology investment. With 80% of the electricity capacity of the Southern Africa Power Pool [3], South Africa is one of the most carbon-intensive countries in the world [4]. Economic growth has been driven largely by the abundance of local coal resources, which currently satisfies about 77% of South Africa's primary energy needs [5]. The accessibility of coal has resulted in a dependence on low-cost coal-fired electricity, energy intensive mining, and heavy industry [6]. Regardless, the South African government aims to reduce greenhouse gas emissions significantly, hoping to cut down on emissions by 42% by 2025 compared to a business-as-usual scenario [7], and the Department of Energy in South Africa plans to achieve 30% clean energy by 2025 [5]. In order to satisfy these goals, enormous changes in infrastructure must take place. One essential change in infrastructure is a move from coal-fired electricity to electricity generated from renewable sources—namely, biofuels, wind, solar, and imported hydropower. The major players in the electricity sector of South Africa are Eskom and the Department of Energy. Eskom generates approximately 95% of the electricity used in South Africa and 45% of the electricity used in Africa, and was converted from private to public in 2002 [8]. With stakes in the Cohora Bassa hydroelectric scheme in Mozambique, South Africa can import 1400 MW of firm energy, plus an additional 300 MW of non-firm energy [9]. Although renewable sources are occasionally used for rural areas that cannot feasibly connect to the national grid, commercially viable renewable energy capacity is not yet exploited on a large scale. Domestic hydropower capacity is small compared to other sources, less than 2% of current energy production, and has been almost fully developed [4].

There are few operational wind power plants in South Africa. Sere Wind Farm, to be among the largest wind farms, would be built near the city of Vredendal in the Western Cape by Eskom [10]. There has also been interest in South Africa to build large-scale PV and CSP to exploit its solar resource. Winkler [11] found that CSP is the most affordable renewable energy option for decreasing emissions in South Africa. Although there are no existing large-scale CSP plants in southern Africa, the South African electricity utility, Eskom, has recently invested in planning a 100 MW CSP plant in the Northern Cape near the city of Upington [8], and the South African government is promoting a 5000 MW solar park in the Northern Cape [12].

The implications of possible changes in usable wind and solar potential must be well understood for future planning purposes. Wind speed and cloudiness are strongly influenced by local temperature gradients as well as large-scale climate oscillations such as the El Nino Southern Oscillation (ENSO) and Madden-Julian Oscillation (MJO), which could behave differently in the future [13]. Meehl et al. [14] report that peak wind speeds will likely increase with increasing temperatures, and Hazeleger [15] suggests that the trade winds in particular are likely to change. Land surface changes can affect local cloudiness and could be amplified in urban areas [16], but making connections between climate change and changes in solar irradiation is a complicated matter [1]. In fact, understanding the impacts of climate change on both aerosols in the atmosphere and boundary layer wind speed are problematic because of the spatial scale of current General Circulation Models (GCMs). Studies have been begun to elucidate the impact of climate change on wind and solar parameters, but the subject is less studied than the impacts on biophysical sectors, e.g., agriculture.

1.1. Wind speed and solar irradiation in a General Circulation Model

A general concern regarding GCM outputs, in particular with any plausible future of renewable resource availability they may project, are the inherent uncertainties of climate modeling and the fidelity of their solutions. The full spectrum of this concern is outside the scope of this study. Rather, in order to assess the appropriate use of GCM output within the context of our study, we must recognize how wind and solar variables are represented. In a GCM, wind speed is explicitly resolved as an average over a finite volume (typically a cube) in space. In addition, some GCMs provide wind speed output at 10 m, an estimation derived from the wind speed values of the atmospheric layer closest to the surface. Vertical layers in a GCM are typically discretized with respect to air pressure, meaning that the layers' altitude change in space and time. These layers are also unevenly distributed so that a finer resolution is achieved near the surface. In a typical GCM, the atmosphere is modeled with about 10–20 layers reaching to about 30 km. GCMs also represent the climate at a coarse horizontal resolution of about 250–600 km [17]. The problem with dividing the atmosphere into large cubes is that atmospheric processes occur at smaller scales. These relatively large finite volumes within GCMs are not ideal for modeling changes in smaller-scale winds (i.e. at the spatial extent of wind farms), which is highly dependent on the effects of elevation, surface roughness, and convection. Clouds and other aerosols can also change at smaller scales than a typical GCM grid. Cloud feedbacks in particular are considered the highest uncertainty in current GCM practice [18]. Cloud cover fraction output is usually estimated based on relative humidity values in each GCM cube. These small-scale processes must be represented as a function of the larger scale variables that are explicitly resolved at the GCM grid or finite volume – otherwise referred to as a "parameterization". For studies that consider the large-scale atmospheric processes and their potential impact and interplay with "sub-grid" processes, parameterizations are an integral part of GCM projections that assess the potential of future changes in the climate system [18]. For all of these reasons listed, GCMs impart substantial uncertainties in resolving wind and solar variables. Although, in spite of the shortcomings of the GCMs, these models are the most well-trusted future projections available of the global climate—of which wind and solar are integral processes—and include state-of-the-art techniques in the field of climate science.

1.2. Previous attempts to characterize the future wind and solar state

In the past, climate change impact studies have typically involved one of two approaches: (i) a climate sensitivity analysis using a wide, unguided range of future climate possibilities; or (ii) use of select climate model output, typically Global Circulation Models (GCMs) from the Coupled Model Intercomparison Project (CMIP), commonly referred to as the Intergovernmental Panel for Climate Change (IPCC) Fourth Assessment Report (AR4) models. The output of these models is applied directly in a climate change impact-modeling framework to assess the impacts of climate change, resulting in a limited set of future scenarios. Research on the climate change impact on wind and solar resources follows a similar pattern, although recently there has been more activity within the latter of these two methodologies.

Pryor et al. [19] attempted to estimate changes in the mean and upper percentile of wind speed in northern Europe. They used daily output from ten GCMs from the AR4 scenarios, fitting a regression model that predicts Weibull distribution parameters from station data. The model was calibrated using mean and standard deviation of 500 hPa relative vorticity and mean of daily sea-level-reduced pressure gradients from the historical GCM runs. Then, using future outputs of the predictors, they provide 10 possible futures of both the wind speed and wind power state, predicting the mean and 90th percentile of each. They found that there was not much

Please cite this article in press as: Fant C et al. The impact of climate change on wind and solar resources in southern Africa. Appl Energy (2015), http://dx.doi.org/10.1016/j.apenergy.2015.03.042