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The impact of climate change on the wind energy resource of Suriname using Regional Climate Model (RCM) simulations

Naresh Ramsingh, Riad Nurmohamed

Abstract— **The objective of this study was to analyze if wind energy would be efficient to use in Suriname, in order to generate power on utility scale. For this study three locations along the coast of Suriname were used: Nieuw Nickerie, Paramaribo and Galibi. The PRECIS regional model was used to do the dynamical down scaling and was also used to do correlation analysis with the available measurements. Two future time periods were used, the period of 2020-2050 and 2070-2100. The ERA40 and ECHAM4 data sets showed a correlation higher than 0.4 with the observed data set. ECHAM5 and Hadley had a very low correlation factor. Based on the ECHAM4 data, three SRES scenarios were available, namely ECHAM4 A2 (2020-2050), ECHAM4 A2 (2070-2100) and ECHAM4 B2 (2070-2100). These wind speed data were corrected and then synthesized on different heights with the simulation program Windographer. This program was also used to do power prediction on different heights and with different wind turbines. The results showed that for the period of 2020-2050, the ECHAM4 A2 (2020-2050) scenario had reasonable wind speeds that could generate power on utility scale with a CF that is in between 20 and 35%. The ECHAM4 A2 (2070-2100) and ECHAM4 B2 (2070-2100) scenarios were scenarios with very low wind power and CFs lower than 20%.**

Index Terms— **Climate change; PRECIS; Suriname; Wind; Windpower**

I. INTRODUCTION

Use italics for emphasis; do not underline. Modern lifestyles demand a continuous and reliable supply of energy for the human development [1]. The Earth's climate is mainly changing because of energy-demanding human activities, mainly from fossil fuel energy usage [2], [3]. The fossil fuel usage and land use change cause globally an increase in carbon dioxide concentrations, while increases in methane and nitrous oxide are primarily related to agriculture [3], [4]. Globally, an increasing rate of warming took place over the last 25 years [5], [6]. Some researchers predicted an average temperature increase around the world from 1 to 3.5 degrees by 2100 [7] and other also refer to an increase of 1 to 5 degrees in temperature over the next 100 years [5]. The changes in temperature will lead to changes in the wind climatology. The IPCC report of 2013 stated that alternative energy sources should be implemented over the next 20 to 30 years to help reduce greenhouse gas emissions and there is widespread recognition at the national and international levels of the importance of renewable energy technologies as a means of reducing carbon dioxide emissions to minimize climate change [5], [8].

Wind power is one of the most attractive renewable energy technologies, because of its high efficiency and low pollution [9], [10], [11], [12]. Therefore in the year 2010 worldwide 83 countries used wind energy for electricity generation [13] and the European Wind Energy Association (EWEA) estimates that 12% of the world's electricity will be generated from wind power by 2020 [14]. Brazil is the second fastest growing wind market in the world with an energy generation of 3.4 GW in 2013. Behind Brazil, follow Mexico, Argentina and Chile. Brazil's wind energy production has escalated up from 22 MW in 2003 to 602 MW in 2009 [15]. Most studies that have examined patterns or trends in the wind resource in several different geographical locations give an increase or decrease in wind speed over different geographical locations for the period of 1956-2006. For example, Klink (1999, 2002) noted a decrease in the annual mean daily wind speeds across the northern US plains. Keimig and Bradley (2002) showed that for a majority of stations in their analysis across western Canada and Alaska there has been a decrease in wind speeds. Pryor et al. (2005a) evaluated wind speeds and wind energy output over a 30-year period (1961–1990) across northern Europe. This study used the Weibull distribution parameter to model the wind probability density function (PDF) and noted an increase in wind speeds over northern Europe (see also Pryor and Barthelmie 2003). In a similar study Garcia-Bustamante et al. (2008) examined monthly wind energy trends over a 5-year period in Spain using a Weibull distribution. They noted no specific trend in the data, although such a short time period does not lend itself to long-term trend analysis. However, they did point out that that energy calculations using a Weibull fit results in an underestimation of total wind energy. Using re-analysis data, Najac et al. (2009), examined 10-m wind speed patterns in France, using data from 1971 to 2002. They found a decrease in wind speed, especially in the Mediterranean area. Many other studies have also pointed out a stilling of the wind in different locations across the globe. For example, Pirazzoli and Tomasin (1999, 2003) reported decreasing winds, especially easterly winds, in the Mediterranean and Adriatic Areas. Tuller (2004), who noted a decrease in mean annual winter wind speeds, has reported a decrease in winds elsewhere in British Columbia. McVicar et al. (2008) reported a decrease in over 88% of the stations overland in Australia for the period 1975–2006. A more recent study (McVicar et al. 2010) compared the patterns of temporal wind speed changes at different mountain locations (China and Switzerland). For these locations, the noted a decrease in winds, and a strong seasonal component, with the trends showing a strong topographical

Ramsingh, N, MSc in SMNR programme, Anton de Kom University of Suriname, Paramaribo, Suriname, 465558 tst 2355.

Nurmohamed R, MSc in SMNR programme, Anton de Kom University of Suriname, Paramaribo, Suriname, 465558 tst 2355, 8500238

component as well, as the patterns ranged from approximately 0.005 to 0.025 m/s per kilometer per year in winter. As they report, wind speeds ‘has declined more rapidly at higher than lower elevations’. In a similar study over China, Jiang et al. (2010) analyzed wind speed changes in China over 1956–2004. They noted a broad decrease in annual wind speed, and in days of strong wind and in maximum wind. They also found small increases in some locations, including the Tibetan Plateau and Guangxi. A study of wind patterns from the Czech Republic identified a statistically significant reduction in mean wind speeds in all months, seasons, and annual values over the period of 1961–2005 (Brazdil 2008). Pryor et al. (2009) have examined wind speed trends over the contiguous USA. They note an ‘overwhelming dominance of trends toward declining values’ for the median values and for annual wind speeds.

The Surinamese energy sector is mainly based on hydropower and diesel generators [16]. It is therefore very important to evaluate other available renewable energy resources. The scientific and policymaking communities acknowledge that black carbon plays a role in climate change by heating our planet, altering precipitation patterns and cloud formation. Diesel engines are one of many sources of black carbon emissions. Suriname is located north of the equator, in the northern part of South America (1.5-6o NL, 54-58o WL) along the Atlantic Ocean. The main objective of this research was therefore to determine if the ongoing climate change could be beneficial for Suriname by introducing alternative energy resource, namely wind energy, into the current energy sector. For this research climate model data of the Hadley, ECHAM5 and ECHAM4 model were used for the period of 2020-2050 and 2070-2100, whereby the downscaling was done by the regional climate model PRECIS. In order to simulate the output power, a careful wind turbine selection took place. The study area of this research was the coastal plain of Suriname, namely: Nieuw Nickerie, district Paramaribo and Galibi (figure 1).

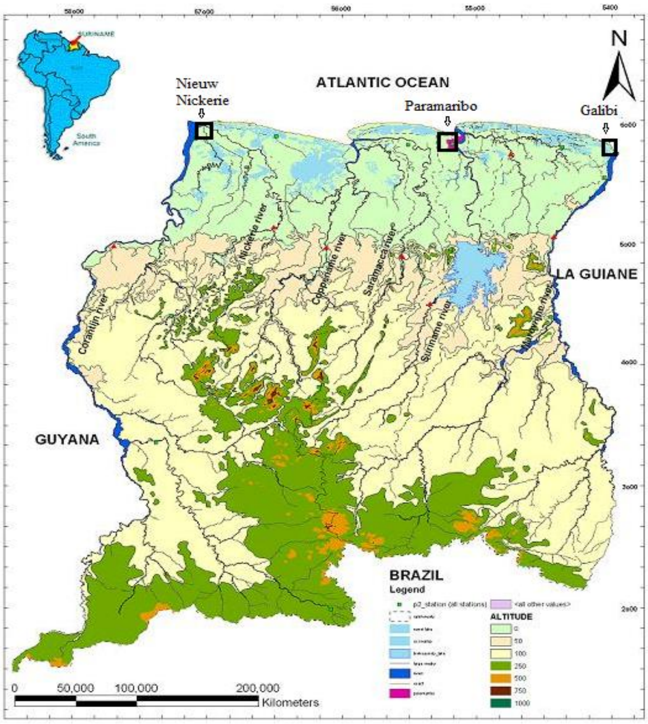

Fig. 1. Locations in Suriname that were of interest for the study. Nieuw Nickerie, district Paramaribo and Galibi.

II. METHODOLOGY

Observations of stations Galibi and Nieuw Nickerie were used; only one year of data (height of 20 m and 30 m, with a time interval of 10 minute) was available (2009-2010). Only the station Nieuw Nickerie had historical data (on a height of 10 m) for a period of 7 years (1981-1987). The second data set available are the GCM data of the ECHAM5, ECHAM4, ERA40 and Hadley model, whereby the A1B, A2 and B2 SRES scenario was taken into consideration from the four SRES scenario families (A1, A2, B1 and B2). The downscaling was done by PRECIS. This data was used to do past (1960-1990), present (2020-2050) and future (2070-2100) climate simulations. The GCM data was based on a 10 m. Linear correlation analyses was used to fill in caps in observed time series and select the best model output data.

A. *Data Analysis*

The software PRECIS performed the downscaling of the different GCM model. The forecasting of the wind speed of Suriname was on daily basis, but only the wind speed of district Paramaribo, Galibi and Nieuw Nickerie were of interest for this study. For ERA40 (1968-1986), ECHAM4-Baseline (1969-1988), ECHAM5 A1B (1960-1989) and HADLEY-baseline (1960-1988) data, the average monthly value was determined per year for the given period. Observed average monthly wind data was correlated with the average monthly value of each model for the same period and location. The correlation is represented in table 1.

Table 1: Model correlation (R2) of the observed data with different RCM model output data

	Hadley baseline	**ERA40**	**ECHAM4 baseline**	**ECHAM5 A1B**
1981	0.27	0.44	0.31	0.15
1982	0.06	0.21	0.26	0.23
1983	0.42	0.60	0.64	0.07
1984	0.39	0.54	0.31	0.07
1985	0.53	0.7	0.45	0.01
1986	0.16	0.74	0.62	0.02
1987	0.15	X	0.31	0.01
R^2	0.19	0.45	0.41	0.03

Note: X means no ERA 40 data available to correlate with MDS data

From the results presented in Table 1, ERA40 has the highest correlation coefficient. ECHAM4 was chosen with the second highest correlation coefficient of 0.41 for Nieuw Nickerie. Due to poor historical data for Paramaribo and Galibi, the correlation with the different RCM models could not be performed and the assumption was made that ECHAM4 also had a high correlation coefficient for these two locations. Hadley and ECHAM 5 were not of interest due to the low correlation coefficient. The ECHAM simulated data set was based on 10 m height, but in order to compare the wind speed on different heights, this data set had to be extrapolated. This could lead to a better understanding of the vertical wind shear profile. The corrected ECHAM4 A2 and ECHAM4 B2 data was and then used as input data for the software program “Windographer”. This software has the ability to do projections of wind velocities of a location on different heights. The average month value of the 10 m ECHAM4 data of the two SRES (A2 and B2) scenarios with different time interval (2020-2050 and 2070-2100) was synthesized at a height of 30, 50, 70, 90 and 110 m with a time step of 24 hours (1440 minutes) and a constant power law exponent of 0.14. The data could be synthesized with power law or log law, but the difference between those two options was negligible, therefore power log was chosen.

B. *Turbine selection*

Based on the United States Department of Energy-, IEC 61400-1 wind turbine classification and the wind turbines classification of Katsigiannis et al (2013), the wind turbines for district Paramaribo, Nieuw Nickerie and Galibi were selected. This was done for each synthesized wind speed for the different height. The census of 2012 registered for district Paramaribo about 250,000 inhabitants with an area of 182 km2 and in Nieuw Nickerie district about 13,000 inhabitants. In these two districts, the energy demand lies in the MWs and the synthesized wind speed were relatively low; therefore, the selected turbines were Class 3 and 4 and Utility-Scale Energy Use (1.5-7.5 MW) based wind turbines. These turbines can operate at a low cut in speed and relative low rated output speed. In order to choose the best wind turbine a procedure was followed. First, the Class 3 and 4 wind turbines with an output of at least 1,500 kW and a hub height of 30, 50, 70, 90 and 110 m were selected out of the Windographer library. The hub heights of the turbines are fixed; secondly, the synthesized data of district Paramaribo and Nieuw Nickerie with the lowest wind speed on different heights was detected. The third step was to simulate the low wind speed data set using the different Class 3 and 4 wind turbines and to identify which wind turbine generated more power using the same low average wind speed with the same hub height. Based on these mention classifications and followed steps the choice was made for the Windtec DF 2000LZ 53.4 CCV on a height of 70 m synthesized wind speeds, the Windtec FC 2000 WT 55 on a height of 90 m synthesized wind speeds and for the Windtec DD 3000-140 on a height of 110 m synthesized wind speeds. Galibi is a small native village with an area of 4,000 ha and about 750 inhabitants, therefore the choice was made for the Endurance E-3120 wind turbine with a hub height of 30 meters.

III. RESULTS

The wind velocity of ECHAM4 A2 (2020-2050) has an average month wind speed between 4 and 5.5 m/s for all three locations except for the month June for Nieuw Nickerie and district Paramaribo, where the speed is lower than 4 m/s. For the period 2070-2100, ECHAM4 A2 and ECHAM4 B2 do not reach the wind velocity of 4 m/s and since the cut-in speed is typically between 3 and 4 m/s, these wind speeds at 10 m height for the period 2070-2100 are not consuetudinary to generate power. Therefore, it was necessary to extrapolate this data. The life span of an average turbine is between 20-30 years [17]. Based on de synthesized wind speed of the three locations the average wind mean power, the average energy output and the average capacity factor was simulated by using Windographer version 3.3.8. This was done on yearly bases for each scenario with an overall loss factor of 17.7%. For illustration purposes, the 30 years average of the mean power, energy output and the capacity factor of each scenario is plotted only for location Nieuw Nickerie in the figures 2-5. For location Paramaribo and Galibi, only the energy output is presented (figure 6-7).

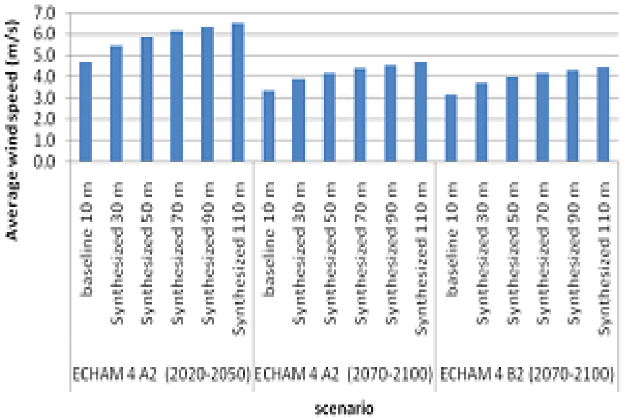

Fig. 2. Average 30 years synthesized wind speed data for different heights and periods at Nieuw Nickerie based on the ECHAM4 model with a baseline of 10 m

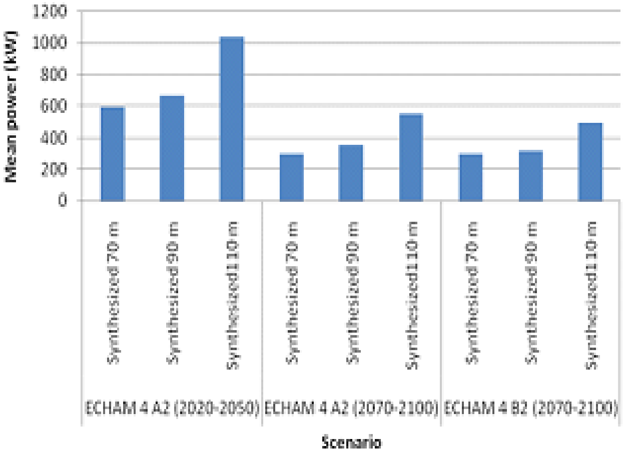

Fig. 3. Mean power at Nieuw Nickerie for different synthesized heights and periods based on the ECHAM4 model

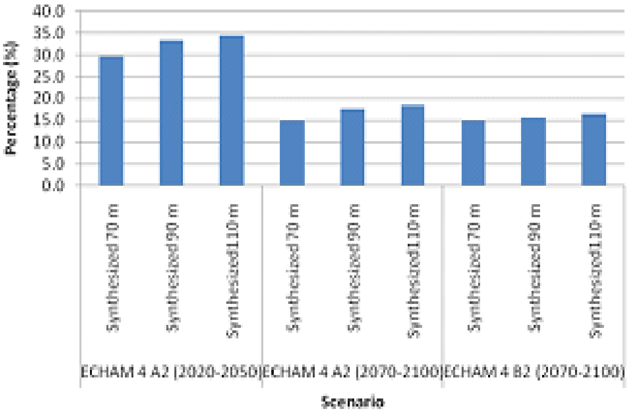

Fig. 4. Capacity factor at Nieuw Nickerie for differentynthesized heights and periods based on the ECHAM 4 model

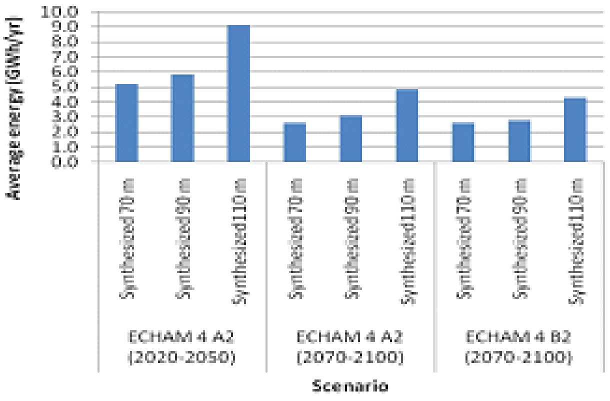

Fig. 5. Energy output at Nieuw Nickerie for different synthesized heights and periods based on the ECHAM4 model

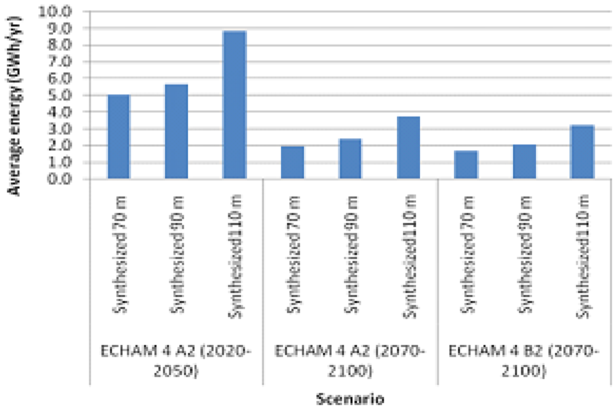

Fig. 6. Energy output at district Paramaribo for different synthesized heights and periods based on the ECHAM4 model

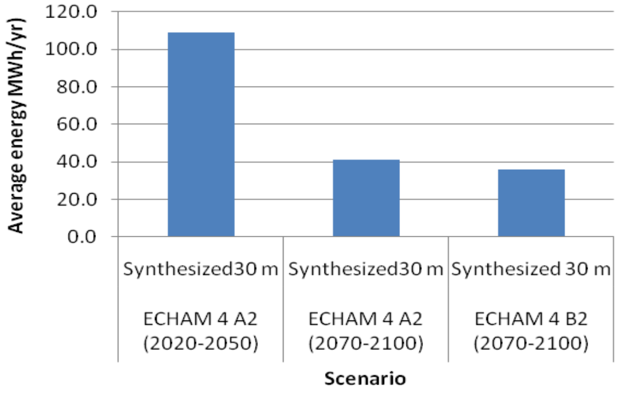

Fig. 7. Energy output at Galibi for different synthesized heights and periods based on the ECHAM 4 model.

IV. CONCLUSION

The focus of this study was based on the wind velocities in the coastal area of Suriname and the power that could be generated by the wind for the period of 2020-2050 and 2070-2100 based on different GCM climate model outputs and SRES scenarios. The 10 m wind speed that had been simulated by PRECIS could not be used in order to generate wind energy for the period of 2020-2050 and 2070-2110, because of the low wind speeds. For the period 2020-2050, Nieuw Nickerie and district Paramaribo had an average month wind speed that was between 4 and 5.5 m/s, except for the month June where it's below 4 m/s and the average wind speed at Galibi was between 4-5 m/s for all months. Since the cut in wind speeds of most wind turbines lies between 3 and 4 m/s it was not efficiënt to work with these wind speeds. For the A2 and B2 (2070-2100) SRES scenario, the average wind speeds were below 4 m/s for the three locations on 10 m height. This results in the conclusion that the 10 m wind speed is not effectief to produce wind energy on utility scale.

The average wind speed extrapolation of 30, 50, 70, 90 and 110 m executed by windographer was evaluated and the different figures showed that the maximum speed varies beween 5.9-6.5 m/s on height of 70, 90 and 110 m for the ECHAM4 A2 (2020-2050) scenario. The CF was in between 20 and 35% for all three locations, which means that wind energy can be generated based on utility scale for the coastal plain for this period.

For the ECHAM4 A2 (2070-2100) and ECHAM4 B2 (2070-2100) SRES scenarios, the wind speed for all three locations were lower than 4.5 m/s, which is just lower than the cut in speed for most wind turbines. The capacity factor varies between 7.5-18.4%. This indicates that the locations are poor wind sites for the period of 2070-2100 and will not be efficiënt to generate wind energy on utility scale during this period. It can be noted that the ECHAM4 B2 (2070-2100) SRES scenario had lower wind speeds than the ECHAM4 A2 (2070-2100) SRES scenario. The wind speed can be coverted to wind power together with a solar system on residential scale, for Nieuw Nickerie and district Paramaribo wind power can be used for pumps in the agriculture sector.

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Ramsingh Naresh MSc was born on 06.03.1983 in Suriname. He received his Master of Science degree in sustainable management of natural resources in 2015 at the Anton the Kom University of Suriname. His research interests are high and low voltage systems, impact of climate change on renewable energy, flora and fauna. Currently he is a teacher at Natuur Technisch Instituut (NATIN).

Nurmohamed Riad PhD was born on 25.06.1974 in Suriname. He received his doctorate degree in technological sciences in 2008 at the Anton de Kom University of Suriname. His research interest are: climate change, water resources management, modeling natural resources systems, development of natural resources information systems. Currently he is a lecturer and researcher at the University of Suriname and the programme coordinator of the master programme in sustainable management of natural resources.