Spatio-temporal Correlation Analysis of Wind Speed and Sunlight for Predicting Power Generation in Jeju

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Abstract

Due to the oil crisis and the insecurity of nuclear energy, the exploitation of renewable energy has attracted researchers' attentions recently. In particular, to charge electric power in smart grid cities, it is important to integrate multiple renewable energy sources efficiently. Unlike the existing energy sources, the renewable energy sources such as wind and solar have low availability because they are uncontrollable. Thus, in order to make stable and predictable electric power generation, many forecasting models have been proposed. This paper examines whether there is any spatio-temporal correlation between wind speed and sunlight, which is not considered by the existing forecasting models for predicting power generation. To achieve this research objective, we categorize and analyze Jeju weather data by regions and seasons. Through the analysis, we show how wind and solar can complement each other. We expect that our analysis scheme can be used as a basis for predicting power generation in smart grid cities where multiple renewable energy sources are combined together.

Keywords: *Renewable Energy, Smart Grid, Wind and Solar, Correlation, Rainfall, Groundwater*

1. Introduction

As the advent of IT convergence, new industries have been created continuously [1]. One of them is smart grid technology. The smart grid technology combines the conventional electricity grid with IT. An issue in the smart grid is to exploit renewable energy such as wind and solar power to supply electric power efficiently [2]. Thus, the research about the interconnection between the renewable energy and the smart grid has been done continuously [3-5]. In addition, many of the existing research works have assumed that the location condition (*spatial* factor) is good enough to generate a specific renewable energy. It is more natural that both location and weather conditions should be considered together because the probability of getting successfully renewable energy from nature is supposed to get higher. For instance, Jeju City became a smart grid test bed in 2009 in Korea. Since then, electric vehicles have drawn people's attention in Jeju, and renewable energy has been considered as a source of charging power supply for the electric vehicles [6]. In fact, since the wind potential of Jeju Island is great, many research works mainly focused on wind energy as renewable energy sources in Jeju [7-9].

However, the weather factors are difficult to predict precisely because they fluctuate very widely. Thus, we cannot figure out how much the amount of the renewable energy generation would be easily [10]. There are various types of models for predicting power production such as physical models, conventional statistical models, and artificial intelligence models, and so on. Among them, the spatial correlation model takes the relationship of different regions' renewable energy sources and improves the forecasting accuracy, compared with the typical time-series models [11].

On the other hand, the weather factors such as wind, rainfall, and sunlight are correlated with each other. Also, the season (*temporal* factor) plays an important role in finding the correlation among the weather factors. If we can figure out how the characteristics of the weather factors would be related with the season, then we can predict the power generation much more accurately. Also, if we produce the steady power by an efficient energy integration policy formulated, due to the easy and precise prediction of the volume of the power production, we can provide the power without any difficulty, which is necessary for charging electric vehicles in smart grid cities.

In the research [12], solar and wind power were analyzed orthogonally in terms of regional correlation. The research proposed that modeling algorithms should be selected on the basis of the coefficient value between regions formulated in the previous work [13]. However, they only focused on the positive correlation between regions without consideration of the relationship between wind and solar. While the positive correlation indicates the *similarity* between regions, the negative correlation indicates the *difference* between regions. The negative correlation is also meaningful for the prediction of power generation. However, even though it is possible to predict the power generation by having the existence of correlation, the correlation analysis not enough to examine the regional data. It cannot explain how much different there is between the regional characteristics.

Thus, we analyze the wind speed and the amount of sunlight on Jeju Island using ANOVA (analysis of variance) as well as correlation analysis as a basis for predicting power generation in this paper. And then, we examine how the regional (spatial) and seasonal (temporal) correlations would be represented among the wind speed, the amount of sunlight, and the amount of the rainfall in four regions: Jejusi, Seogwipo, Seongsan, and Gosan. We conduct this research using the data collected in Korea Meteorological Administration from 2000 through 2010 [14].

The rest of this paper is organized as follows. In Section 2, we describe the previous research about renewable energy and power generation, especially in Korea. In Section 3, we present the results of the correlation analysis and ANOVA by seasons and regions. And then, in Section 4, we perform the correlation analysis among wind, sunlight, and rainfall for the purpose of finding out whether there is any predictable component in their relationship. Finally, we conclude our paper in Section 5.

2. Background and Related Works

Since this research is interested in the energy generation mechanism that combines the wind and the solar, we firstly examine the previous research related to the state of the art of the wind and solar power plant in Korea. According to [15], the sunlight draws a normal distribution curve with a peak at 1 pm. The wind energy is continuously produced for 24 hours, but there is more productive during night. Spring and autumn are more productive in case of the solar energy, whereas winter is more productive in case of the wind energy, compared with other seasons. Also, the sunlight depends on daily time and season, whereas the wind speed depends on the location of the power plant built [15].

Next, there was a study on examining two types of relationships: peak load-sunlight power and peak load-wind power [12]. According to the study, the wind power has no correlation with the peak load and the solar power has a little correlation in Korea. It indicates that both of the energy sources can hardly contribute to preventing the shortage of electricity during peak load time and the power cannot be predicted only with the energy sources such as wind and solar. In addition, in order to check out if the regions had similar patterns in wind and solar power, the study analyzed how the positive correlation among regions would be. If there is a positive correlation between two regions, when one region has low renewable energy power, the other region also has low renewable energy power. Thus, the renewable energy power is predictable, but the shortage of electricity cannot be covered during peak load time. In that case, it is required to prepare another energy source for the stable power generation. On the contrary, in the case that the regions have no correlation with each other, when one location has a low power, another may support the electricity. Thus, the correlation can determine the modeling method to generate renewable energy power.

However, the research above has a few limitations because it examined only the positive correlations in the wind and the solar, respectively. In modeling the renewable energy sources, difference as well as similarity between the sources is important since the difference represented by negative correlation indicates how the sources can be complemented. Unusually, unlike other provinces, the groundwater is one of the most critical power consumption sources in Jeju Island [16]. Recently, there has been research on the use of wind power at groundwater intakes [17]. Therefore, if important energy consumption factors such as the groundwater are considered additionally, more accurate modeling method than the previous research will be made.

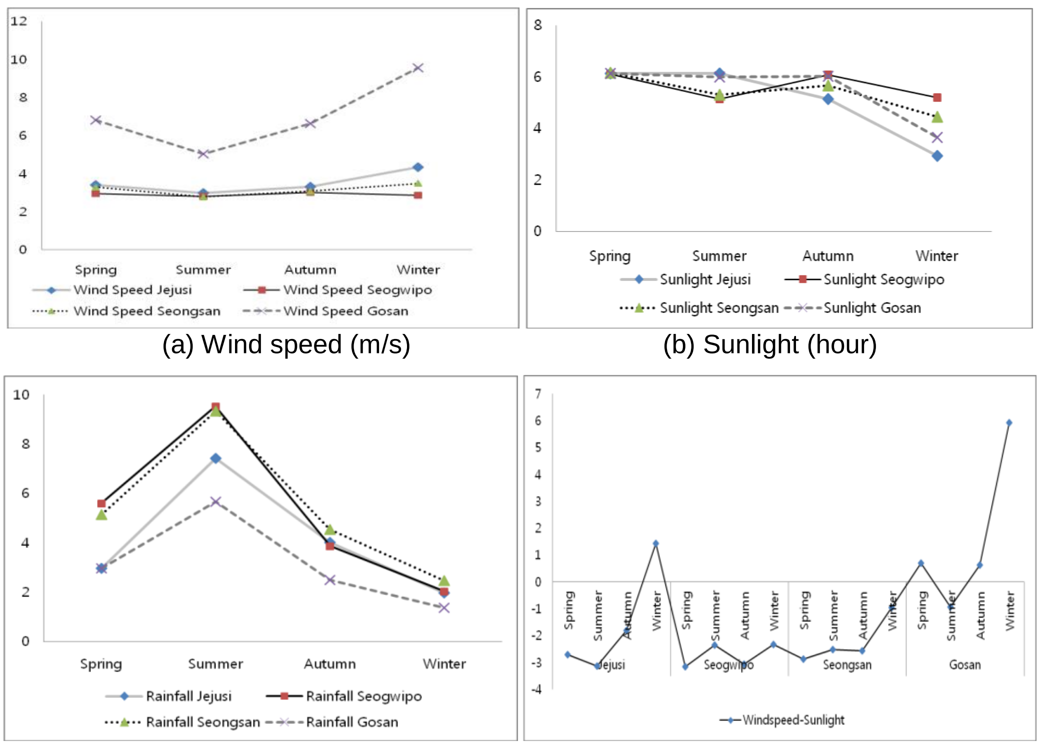
3. Correlation Analysis and ANOVA by Seasons and Regions

In this Section, we firstly present the correlations between the two regions in Jeju in terms of wind speed and amount of the sunlight, respectively. As shown in Table 1, with regard to the wind speed, the correlation coefficients were statistically significant for the most of pairs of regions: Jejusi-Seongsan (.74), Jejusi-Gosan (.96), Seogwipo-Seongsan (.43), and Seongsan-Gosan (.78). Regarding the sunlight, the correlation coefficients were statistically significant for all the pairs of regions. The values were ranged from .53 (Jejusi-Seogwipo) to .92 (Jejusi-Gosan). The coefficients were almost high (greater than .50) and positive. The high and positive value indicates that there exists similarity between two regions paired. However, the result of the correlation in the wind speed was different from the previous research [12] in some parts. The correlation coefficients of Seogwipo (south)-Jejusi (north) and Seogwipo (south)-Gosan (west) were .099 and .035, respectively. The values were low and not statistically significant. The phenomena result from the fact that the wind, which dominates Jeju Island, is out of the northwest, but due to Halla Mountain, Seogwipo is not affected from the wind direction [18]. We should take into account the difference between the north and the south as well as between the east and the west as described in [12].

Table 1. The Correlation Coefficients between Pairs of Two Regions in Terms of the Wind Speed and the Amount of the Sunlight

	Seogwipo		Seongsan		Gosan	
	Wind speed	*Sunlight*	*Wind speed*	*Sunlight*	*Wind speed*	*Sunlight*
Jejusi	**.099**	*.533***	.739**	*.811***	.960**	*.920***
Seogwipo	-	-	.426**	*.856***	**.035**	*.721***
Seongsan	-	-	-	-	.776**	*.903***

Second, we present the seasonal means of the wind speed and the amount of the sunlight for the 4 regions. Figure 1 shows the seasonal means of the wind (a), the seasonal means of the amount of the sunlight (b), the seasonal means of the amount of the rainfall (c), and the seasonal difference between the wind speed and the sunlight (d), respectively.



(a) Wind speed (m/s) (b) Sunlight (hour)

(c) Rainfall (mm) (d) Wind speed – Sunlight

Figure 1. Seasonal means of Wind Speed, Sunlight, and the Rainfall of 4 Regions

Due to the weather condition, in the Figure 1(a), graphs had similar patterns in the 3 regions except Seogwipo. For all regions, the wind speed is the lowest during summer while it is the highest except Seogwipo during winter. In case of the sunlight, spring and autumn have the highest whereas winter has the lowest for all regions. Due to the frequent rainfall, the amount of sunlight of summer is lower than those of spring and autumn. From the graphs, we found out that most of the relationships between the wind speed and the sunlight by regions and seasons are inversely proportional. From the graphs of the rainfall (Figure 1(c)) and the gap value between the wind speed and the sunlight (Figure 1(d)), we can see three facts. One is that the wind speed and the amount of the sunlight were reduced during rainy season. Another is that the wind power was the greatest among the four regions in all seasons with peak during winter in Gosan and was also relatively great during winter and spring in Jejusi. The other is, in Figure 1(d), that the wind speed and the sunlight had different measurement scales and thus there was no meaning as the values themselves. We focused on how the values change. In Figure 1(d), except Seogwipo, it's possible to get more renewable energy from wind than from solar during winter.

Third, in order to examine how much different the values are exactly, we performed the analysis of variation with post-hoc analysis. Table 2 shows the mean differences among seasons and among regions. For all pairs of the regions and the seasons, the wind speed was significantly different. And, the season and the region explained the wind speed about 54.9%. The exact differences between seasons were as follows: .72 (p<.0005, spring-summer), .11 (p=.003, spring-autumn), -.94 (p<.0005, spring-winter), -.61 (p<.0005, summer-autumn), -1.66 (p<.0005, summer-winter), and -1.05 (p<0.0005, autumn-winter). The exact differences between regions were as follows: .61 (p<.0005, Jejusi-Seogwipo), .36 (p<.0005, Jejusi-Seongsan), -3.49 (p<.0005, Jejusi-Gosan), -.26 (p<.0005, Seogwipo-Seongsan), -4.10 (p<.0005, Seogwipo-Gowan), and -3.84 (p<.0005, Seongsan-Gosan).

The amounts of the sunlight were almost significantly different among seasons and regions. The season and the region explained the amount of the sunlight about 93.8%. The exact differences between seasons were as follows: .49 (p<.0005, spring-summer), .41 (p<.0005, spring-autumn), 2.08 (p<.0005, spring-winter), -.08 (p=.216, summer-autumn), 1.59 (p<.0005, summer-winter), and 1.67 (p<.0005, autumn-winter). The difference between spring and winter was the biggest. The exact differences between regions were as follows: -.55 (p<.0005, Jejusi-Seogwipo), -.31 (p<.0005, Jejusi-Seongsan), -.36 (p<.0005, Jejusi-Gosan), .24 (p<.0005, Seogwipo-Seongsan), .19 (p<.0005, Seogwipo-Gosan), and -.05 (p<.412, Seongsan-Gosan). The difference between Jejusi (north) and Seogwipo (south) was the biggest.

Table 2. The Effects of Season, Region and Season and Region Interaction on Wind Speed, Sunlight and Rainfall

	Wind Speed		Sunlight		Rainfall	
	F	*P*	*F*	*P*	*F*	*P*
Season	734.83	.000	423.95	.000	479.80	.000
Region	5806.09	.000	26.61	.000	84.03	.000
Season & Region	269.96	.000	49.84	.000	10.46	.000
	$R^2 = .549$		$R^2 = .938$		$R^2 = .552$	

In case of the rainfall, the correlation coefficients were high for all the pairs of regions (from .87 to .93). However, the mean differences between regions were statistically significant (all p < .0005) in Jejusi-Seogwipo (-1.16), Jejusi-Seongsan (-1.28), Jejusi-Gosan (.98), Seogwipo-Gosan (2.14), and Seongsan-Gosan (2.26). Also, the mean differences between seasons were statistically significant in some parts (-3.61 in spring-summer, 1.74 in spring-winter, 3.30 in summer-autumn, 5.36 in summer-winter, and 2.06 in autumn-winter).

From the results, we found out that the wind speed and the amount of sunlight are positively correlated between the seasons and between the regions respectively. For the wind speed, the difference between summer and winter was the biggest and the difference between Seogwipo and Gosan was the biggest. For the amount of the sunlight, the difference between spring and winter was the biggest and the difference between Jejusi and Seogwipo was the biggest. We cannot apply the same prediction or modeling policies to all regions and to all seasons. Even though the regions had the similar renewable energy source patterns, the mean values for the renewable energy sources were different statistically. In addition, the previous research works have performed analysis only by regions. However, according to Table 1, there were the interaction effects between season and region. In other words, region affected season and vise versa. If we consider the interaction effects (the interaction between temporal and spatial factors) when we establish a power generation model, we can increase accuracy of the model. Also, we should consider the difference between regions and seasons when we model the power generation.

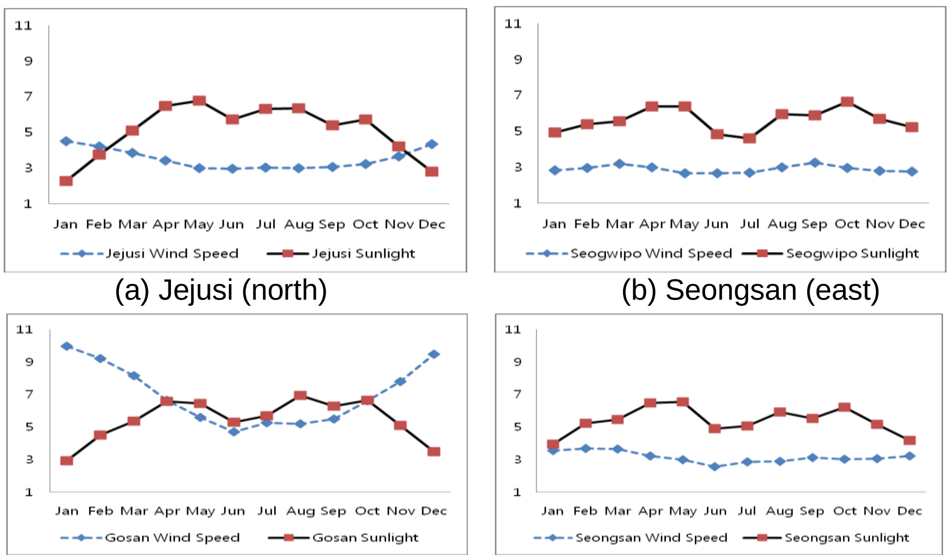
4. Correlation Analysis among Wind Speed, Sunlight and Rainfall

So far, we have analyzed the wind and the solar energy independently. In this section, we present the relationships between the wind and the sunlight. Table 3 shows the correlation coefficients among the wind speed, the sunlight, and the rainfall. From the Table 3, we found that the wind speed and the sunlight are negatively associated with each other especially in Jejusi (north) and Gosan (west). The line for the wind and the line for the sunlight were crossed, and the slopes of the two lines were opposite during spring, autumn, and winter. For all regions, the correlation coefficients are highly negative values (-86.3%, -65.1%, -74.0%, and -74.7%). In summer, rainy season is usually included. The amount of sunlight and the wind speed do not have any meaningful relationship explicitly. Thus, when we establish a power generation model, we should take into account the opposite relationship between the wind power and the solar power.

Table 3. Correlation Coefficients and Monthly means of the Wind Speed, the Sunlight and the Rainfall. (w-s means the Wind and the Sunlight, w-r means the Wind and the Rainfall, and s-r means the Sunlight and the Rainfall)

Region	Coef.	Spring	Summer	Autumn	Winter
Jejusi	w-s	-0.863	-0.43	-0.737	-0.683
	w-r	0.046	0.412	-0.477	-0.268
	s-r	-0.091	-0.69	0.287	0.265
Seogwipo	w-s	-0.651	0.247	0.051	0.252
	w-r	-0.345	0.116	0.574	0.541
	s-r	-0.02	-0.792	-0.285	0.001
Region	Coef.	Spring	Summer	Autumn	Winter
Seongsan	w-s	-0.74	-0.039	-0.24	0.464
	w-r	-0.033	0.487	0.096	0.06
	s-r	-0.124	-0.501	-0.207	-0.239
Gosan	w-s	-0.746	0.035	-0.631	-0.669
	w-r	-0.363	0.244	-0.456	-0.394
	s-r	0.105	-0.571	-0.004	0.299

Next, we examine the relationship between the wind speed and the rainfall. The coefficients between the wind speed and the rainfall were not high due to the rainy season in Korea, the coefficients in summer is positive (Jejusi: 41.2%, Seogwipo: 11.6%, Seongsan: 48.7%, Gosan: 24.4%). The result was the same as those described in the research [19]. However, during other seasons, each region had different relationship between the wind and the rainfall. For instance, in Gosan, except summer, all season had negative correlation (spring: -36.3%, autumn: -45.6%, winter: -39.4%). In Seogwipo, autumn and winter had positive correlation coefficients, 57.4% and 54.1% respectively, unlike Gosan. From this analysis, we knew that the amount of the rainfall is also an important factor when we consider power generation. Finally, the correlation coefficients between the sunlight and the rainfall were low except summer. And, the values were all negative (Jejusi: -69.0%, Seogwipo: -79.2%, Seongsan: -50.1%, Gosan: -57.1%). It is also related with the rainy season because the amount of the sunlight usually drops during the rainy season. Next, in order to figure out the differences between regions and seasons, Figure 2 shows the monthly means of the wind speed and the amount of the sunlight in the 4 regions. In the previous section, when we analyzed the wind speed and the sunlight of the 4 regions orthogonally, we found out that the patterns for the 4 regions were similar (positive correlation). However, when we considered the two renewable sources together, their correlations were different according to seasons and regions.



(a) Jejusi (north) (b) Seongsan (east)

(c) Gosan (west) (d) Seogwipo (south)

Figure 2. Monthly Means of the Wind Speed and the Sunlight in the 4 Regions

From Table 3 and Figure 2, we can summarize the relationships between regions and between seasons as follows. Firstly, the rainfall affects the wind speed and the sunlight especially in summer. Also, from Figure 2, in summer the values of the wind speed and the sunlight are relatively lower than other seasons. Thus, we should develop other types of energy for power generation during that season. Secondly, since the wind power in winter is higher than in other seasons, we can expect the electric power from the wind. However, the relationship between the wind speed and the sunlight is opposite at that time, the wind power is more helpful than the solar power. Also, the north and the west had more similar than the east and the south and vice versa. It means that we should consider the wind direction and the geographical features in Jeju Island. Next, in spring, even though there are differences among the 4 regions, all the amount of sunlight go up in the 4 regions. Thus, the solar power complements the wind power in spring. Finally, we can see the interaction effects between region and season from Table 3 and Figure 2. It means that we can predict better when we consider spatio-temporal factors at the same time.

5. Conclusions

In this paper, we examined the correlations between the wind speed and the amount of the sunlight in the 4 regions of Jeju Island in order to formulate a more accurate power generation model. The previous research has usually focused on the renewable energy sources independently. Also, the research only focused on the regional similarities for predicting power generation. However, this paper included the negative correlation and the correlation between the wind and the solar to improve the power generation model more accurately. It means that in this paper, we found out the negative relationship between renewable energy sources and prepared a basis of the way for complementing the energy sources with each other.

In addition, we present the necessity of considering the spatio-temporal factors together for predicting power generation by showing the interaction effects between season and region. Also, rainfall is an important factor in Jeju when we model the generation of the renewable energy. Finally, unlike other provinces, the groundwater is one of the most important resources in Jeju Island. It can be the greatest consumption factor with electric vehicles in smart grid. Thus, in Jeju Island, the study on analyzing the relationship between the renewable energy sources and the groundwater will be needed in the future.

The weather factors are correlated and fluctuating. Thus, it is not easy to predict the amount of the renewable energy sources due to the intermittency. However, by using the results of this paper, we can choose more appropriate modeling method to generate stable electrical power in the future. Since our research relied on the data, the results may be straightforward and experimental. More sophisticated experiment should be performed in the near future.

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