FLC-based Renewable Wind Energy Viability Assessment in Central Luzon Philippines

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***Abstract*—In this paper, the proponent designed and developed a fuzzy logic based control system for renewable wind energy viability analysis specifically in six selected sites in Central Luzon Philippines. The membership functions (MFs) were constructed for three classified parameters: wind resource density, other wind resource parameters and site-related criteria with 5%, 5% and 90% factor rates. The quantitative site assessment made by Karen Conover of Global Energy Concepts (GECs) was used for constructing the MFs and for establishing the 216 fuzzy rules using Sugeno-style of fuzzy inference system. The average score of selected sites were used for fuzzy logic assessment and it was realized that Sual Pangasinan and Carranglan Nueva Ecija are best suited for possible wind farm development considering that the linguistic assessment was "Very Good" while the rest were just "Good". The results obtained using fuzzy logic and the reviewed literature was compared and a favourable correlation was observed. This means that the FLC-based wind viability assessment could be used as an effective computational tool for Central Luzon and even for other wind energy viability assessments inside and outside the country.**

***Index Terms*—Fuzzy Logic; Matlab Toolbox; Renewable Energy; Sugeno-Style; Viability Analysis; Wind Energy; Wind Farm Development.**

I. INTRODUCTION

The Energy Information Administration (EIA) defined Renewable Energy Sources as *Fuels that can be easily made or "renewed."* Different types of renewable fuels include hydropower (water), solar, wind, geothermal, and biomass. Wind energy is one of the many types of renewable energy. It is easily made and could be re-used. It is mainly used to generate electricity. One of the advantages of this type of energy is that the resources is provided from the environment rather than using other materials such as fossil fuel. It is also less harmful as it is clean and does not produce harmful emissions. It is also a fast source of energy resource and is growing. Wind energy is considered renewable because it is derived from the sun and is capable of being replenished on a reasonable time frame [1].

For the record, wind energy is one of the fastest growing energy resources in the world. In United States, wind energy has shown tremendous growth as alternative source of electricity among renewables in the past years. Texas leads the country in installed wind capacity with around 20 % of its current capacity. In European countries, Germany generates 22% of its electrical power via wind power (34,000 MW wind capacity installed), UK installed 1883 MW new wind capacity in 2013. This accounts for more than 20% growth, able to surpass new installed wind power in the U.S. In Asia, China added 16,100 MW new capacities in 2013, which is 21.4% annual growth. This makes China doubles its wind generating capacity as compared with any other country other than the U.S. The rapid growth in wind power can be attributed to only two things – cost reduction in electricity production and more interest in renewable technologies. In developing countries like the Philippines, wind farm development is essential [2].

Wind energy can become a viable source of renewable energy in the Philippines. The Philippines, an archipelago, consists of more than 7000 thousand islands and is surrounded by water. These bodies of water assist in producing wind and increase the potential of creating renewable energy with the use of wind turbines. If wind energy is properly utilized, it can increase the power and electricity in the country. This study will aim to determine if it is efficient to produce electricity in the Philippines through wind energy. For wind energy to be efficient, it should be installed in higher locations in which air will flow faster. It is also important that the surfaces do not block the air currents.

A. Background of the Study

Quantifying and analyzing wind energy potential and wind farm development is becoming a need and research trend in the Philippines. Providing the country with the tools necessary to identify the best wind energy development opportunities is essential in facilitating, catering and delivering alternative source of energy. In due course, support from the Philippine government is vital. Policies affecting wind energy development and updating related previous works is a must in promoting and supporting renewable wind energy viability analysis. In the Philippine context, Global Energy Concepts (GEC) collaborated with the Philippine National Power Corporation (NPC) in performing comparative analysis of selected sites in Central Luzon for possible wind farm development. The specific areas being studied in Central Luzon are Sampaloc in Rizal, Caliraya in Laguna, Sual in Pangasinan and Pantabangan, Puncan-Digdig and Caranglan in Nueva Ecija respectively. These six sites were visited by GEC as recommended by NPC and its foreign counterpart agency: U.S. Agency for International Development (USAID). In addition, the U.S. Department of Energy (DOE), through the National Renewable Energy Laboratory (NREL), has been working closely in the quantification of wind energy sources in the country [1].

In the study, entitled, "Philippine Wind Farm Analysis and Site Selection Analysis" dated January 1, 2000 to December 31, 2000 by Karen Conover of Global Energy Concepts, it was realized that there were two areas out of six identified sites that achieved the highest rankings. North Carranglan in Nueva Ecija and South Sual in Pangasinan ranked the most, but not in terms of highest estimated wind resource. It ranked the most because it is more conducive than other compared areas with higher estimated wind resources. This means that terrain is a crucial factor in wind farm development. Moreover, it was stated that one common consideration in the screening process of all sites is the lack of quality measured wind speed data. It was also noted that on-site wind speed measurements should be made at different sampling locations in providing more accurate assessment of wind resource potential [1].

B. Objectives of the Study

The prime objective of this study is to elicit renewable wind energy viability assessment in Central Luzon Philippines.

Specifically, this study aims to:

a) present relevant literature reviews on wind energy resource in foreign and local context,
b) develop and illustrate a model of fuzzy logic for representing viability of wind resource
c) construct membership function and derive fuzzy control rules for renewable wind energy viability analysis, and
d) simulate and verify the performance of the fuzzy system.

II. Literature Review

A case study was conducted in determining the local economic benefits of wind energy in New Zealand. The case study looks at the economic activity created by the construction and operation of Stage 3 of Taurua wind farm. The Taurua 3 project costs 170 million dollars. Wind turbines were purchased and delivered from Europe. It was realized that the economic benefit to the wider Manawatu economy was greater than the direct project spend. Civil works at the site alone involved 200,000 man hours over a 12-month construction period. This created 100 full-time equivalent jobs. Over $7 million was paid out in salaries, much of which flowed on to the wider. Many other companies supplied equipment and services to contractors on site. And hotels, restaurants, rental car companies and the airport benefited as people travelled to and from, and worked at, the wind farm site [3].

Wind Energy impacts were researched through multiple studies to determine the environmental benefits of wind energy. The ecological impacts, impact on humans, health, cultural, visual, noise, local economics and land use were obtained. It was concluded, that we must decide that if we have to produce electricity, it is certainly preferable to produce it in a way which has the smallest possible impact on the environment. From a technical and economic standpoint, the most mature form of renewable and "clean" energy is wind energy. It can effectively contribute to combating climate change while at the same time providing various environmental, social and economic benefits. On the other hand, it is necessary to minimize the impact of the wind energy, particularly in terms of environment (preservation of protected areas) and human health (noise and visual impact) [4].

Other reviews, studies and literatures relating to wind turbines and human health such as case studies from the Public Service Commission Staff for the Wisconsin State Legislature and New Zealand Wind Energy Association reveal that there is lack of evidence that can demonstrate wind turbines being harmful towards human health. It also can provide economic benefit for businesses and would create employment aside from energy [3],[5].

Wind and Energy Projection of the Philippines was forecasted by the Ateneo Innovation Center in collaboration with Alternergy Philippine Holdings Corporation and Manila Observatory. Their study focused on long-term wind projection prospecting and next-day wind forecasting. This study characterizes a wind farm site in Pililla, Rizal for its potential wind power production from 2013 to 2037. The results showed that the site in Rizal will experience an increase in power production in the future. It will have no gain in the last five years of its lifetime when compared to the baseline. The increase in power production will decrease the levelized cost of energy for this technology [1].

A study regarding the wind energy potential in the Philippines by the Philexport Industrial Studies Department and Board of Investments identified potential locations for high wind electricity. The Philippines' potential for wind energy is attributed to its many good wind sites due to its location in the Asia-Pacific monsoon belt and its potential wind power seems sizable compared with other power producing countries like the US and India. US NREL – DOE study showed that out of the 73 provinces in the Philippines, 47 have at least 500 MW wind potential and 25 have at least 1,000 MW. The following locations were identified in the US NREL study to have a potential wind electricity capacity of 76,600 MW over an area of 10,000 km²: 1. Batanes and Babuyan Island, 2. Northwest tip of Luzon (Ilocos Norte), 3. Higher interior terrain of Luzon, Mindoro, Samar, Leyte, Panay, Negros, Cebu, Palawan, Eastern Mindanao and adjacent islands, 4. Well-exposed east-facing coastal locations from Northern Luzon southward to Samar, 5. The wind corridors between Luzon and Mindoro (including Lubang Island), and 6. The wind corridors between Mindoro and Panay (including the Semirara & Cuyo Island) [6].

Moreover, the study of K. Conover about Philippine Wind Farm Anaysis and Site Selection Analysis is about finding a location that is suitable for windpower facility construction in the Philippines. According to their study, there are only eight places that wind power facilities can be built in the country. All of those eight are along the central and nearby areas of Luzon. Wind viability methods include screenings of wind resource, land stability, evaluating the factors affecting site stability and so forth. There were only four of those eight places, which were evaluated for possible site construction. This includes Laguna, Rizal, Pangasinan and Nueva Ecija. However, based on their research, those four still needs further analysis and evaluation. This is because their rankings are not really high when it comes to building efficiency of said power facility. Furthermore, the study of Conover explains that these four places in the central luzon specfically Carrangalan, Sual, Puncan-Digdig and Sampaloc are still at risk of having problems in the future. As of conducted study of GEC, these four locations that are prospects of becoming the construction sites are averagely acceptable, but not high enough to be graded. Individually from these four, some are graded high in some aspects, but low on the other which only means that the success grade of lands does just equates the negative factors of it and in some cases, success is just a little higher than the negative, in which if analyzed is just an average ratio of success. Relating to this analysis, this study of Conover does not fully supports the possibility of high efficiency of wind power facilities to be built in the Philippines[2].

III. METHODOLOGY

The framework of the system (shown in Figure 1) is consisted of four main sections. As illustrated, the first important consideration of the study is to meticulously review relevant literatures. The proponent will solicit foreign and local literatures to gather important sources related to wind energy and wind farm development. As part of its objective, the proponent will illustrate a model using fuzzy logic for viability analysis of renewable wind energy in the Philippines. The membership functions will be constructed and fuzzy rules will be established using Sugeno-style of fuzzy inference system to formally present and illustrate the model. Most importantly, the fuzzy system will be tested and verified.

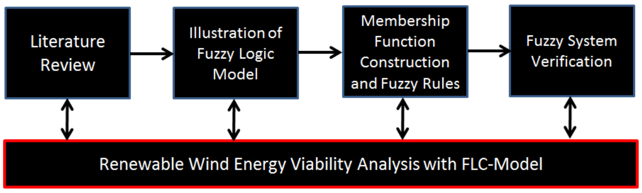

Figure 1: Framework of FLC-based renewable wind energy viability analysis

In providing a mechanism for ranking and prioritizing potential utility-scale wind energy sites in the Philippines, GEC developed a site-screening process. The screening process was developed based on techniques used in the United States and adjusted for application in the Philippines. The result of their work is a five-step process that addresses wind resource evaluation, evaluation of land suitability, analysis of site-specific suitability, preliminary site ranking, and quantitative analysis. In this work, the proponent will create a fuzzy logic model using the quantitative assessment results of GEC in selected sites in Central Luzon. Moreover, the fuzzy logic assessment results will be compared with their results.

In applying the site-screening process, GEC assigned a score in each criterion as shown in Table 1. In their work, the score assigned to the wind resource potential is weighted (multiplied) by a factor of 4 and added to the remaining scores. They considered wind resource density as an important factor for wind farm development. The other 21 criteria have the same weightings of 1. The cumulative scores for each site were computed and compared using averaging technique. Based on cumulative scores, they assigned rankings.

Table 1
Site Ranking Criteria

	Points Assigned (Score)					
Criteria	**0**	**1**	**2**	**3**	**4**	**5**
Wind resource density based on NREL atlas (W/m^2)	< 300	-	300-400	400-600	600-800	800-1200
On-site wind measurements to confirm wind resource	None	Local Opinion	< 1 Year		1-2 years	> 2 years
Quality of on-site measured wind speed data	None	Low		Moderate		High
Correlation of on-site wind speed data with wind atlas estimates	None	Low		Moderate		Strong
Quality and availability of correlated long-term data	None	Low		Moderate		High
Proximity to transmission lines		>20 km	10-20 km	5-10 km	1-5 km	< 1 km
Upgrades required to existing transmission lines		Extensive	Moderate		Minor	None
Terrain		Rugged	Complex		Rolling	Flat
Accessibility		Poor	Marginal		Good	Excellent
Security		Poor	Satisfactory	Excellent		
Terrain orientation to prevailing wind		Poor	Marginal		Good	Excellent
Landowner concerns		High		Moderate		Low
Social acceptability		Poor		Satisfactory		Excellent
Land costs		High		Moderate		Low
Vegetation over 10 m		Significant		Scattered		None
Soil conditions		Solid Rock	Fractured Rock		Soil/Rock	All Soil
PAGASA rank in frequency of typhoon passages over province	1 - 11	12 - 23	24 - 35	36 - 47	48 - 59	60 - 71
Other environmental issues (corrosion, humidity)		Extensive	Moderate		Minor	None
Insects		Many	Moderate	Few		
Cultural or environmental concerns		Extensive	Moderate		Minor	None
Site capacity, MW		<25		25-50		> 50
Aviation and telecommunications conflicts		Extensive	Moderate		Minor	None

A. *Fuzzy Logic*

Lotfi Zadeh is coined to be the father of fuzzy logic (FL). Zadeh described fuzzy logic as a problem-solving control system methodology. Fuzzy logic is a computational tool that simply mimics the decision making of human beings using set of simple rules in a convenient and faster method. In this work, the proponent will apply the concepts and principles of fuzzy logic in the viability analysis of renewable wind energy source in Central Luzon, Philippines. The proponent will describe the identified six sites in Central Luzon in terms of fuzzy linguistic terms (Poor – 0, Fair – 1, Satisfactory – 2, Good – 3, Very Good – 4 and Excellent – 5) called fuzzy sets, *Refer to Figure 2 for this illustration*. There were 22 site ranking criteria identified by GEC as shown in Table 1. In this work, these 22 site ranking criteria will be categorized into three: wind resource density, other wind resource parameters and site-related criteria. The proponent will construct membership functions in assigning values with respect to fuzzy sets and its degrees of membership. In this consideration, triangular membership function as amongst the most commonly used technique which requires three parameter specifications (a, b and c) will be used [7], [8]. The output crisp value can be calculated using the center of gravity formula to assess wind energy viability in each site.

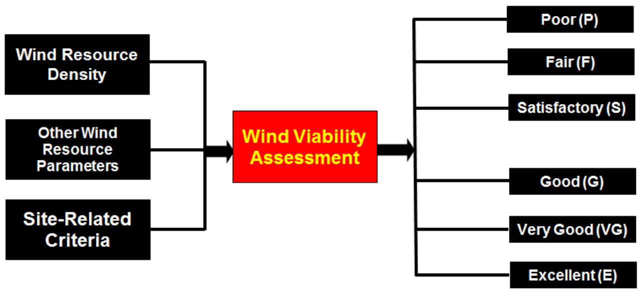

Figure 2: Hierarchical structure of FLC-based wind viability assessment

From the identified 22 site ranking criteria of GEC, the proponent grouped the parameters into three categories to easily assess the viability of wind energy in selected sites in Central Luzon. These are wind resource density (1 parameter), other wind resource parameters (4 parameters) and site-related criteria (17 parameters). These parameters were represented using Sugeno-style of fuzzy inference system (FIS) to provide a concrete wind energy viability assessment (shown in Figure 3). The proponent had given 5%, 5% and 90% factors for the main parameters respectively. These factor rates were based from summarized results of GEC. In getting the values for each main parameter, the proponent simply adds and averages the parameters contained in each block.

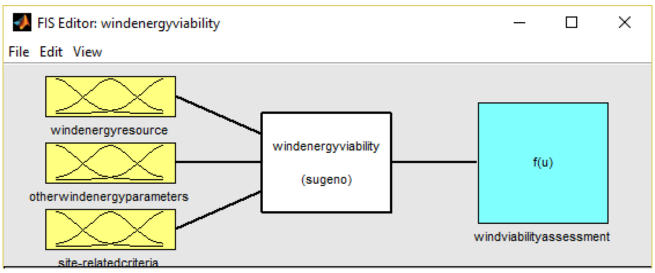

Figure 3: Sugeno-style FIS for wind viability analysis

The proponent constructed the membership functions of each main parameter using quantitative assessment results of GEC. There are six triangular membership functions for each parameter. These membership functions are classified as Poor – P, Fair – F, Satisfactory – S, Good – G, Very Good – G and Excellent – E. The acceptable input values will range from -0.5 to 5.5, considering that the proponent considers scoring of 0 to 5. The constructed triangular membership functions for site-related criteria as shown in Figure 4 are common for the other two parameters (other wind resource parameters and site-related criteria respectively).

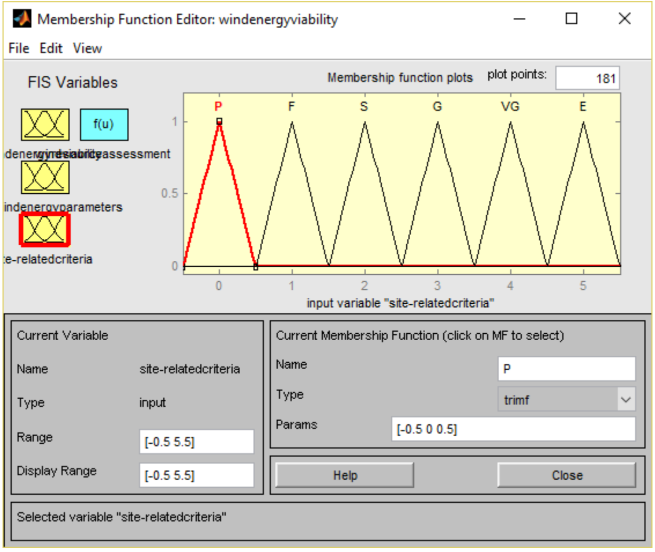

Figure 4: Triangular membership functions for site-related criteria

The output membership function of the system is elicited in Figure 5 below. The proponent make used of Singleton membership function for six classified outputs: Poor, Fair, Satisfactory, Good, Very Good and Excellent with constant values of 0, 1, 2, 3, 4 and 5 respectively. The wind energy viability assessment was patterned from scoring survey sheets collected, tallied and analyzed by GEC.

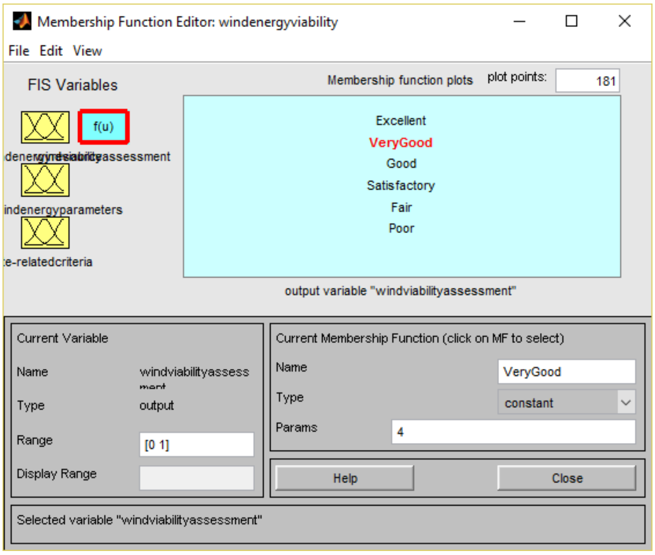

Figure 5: Output membership function of the system

The most important consideration in fuzzy logic assessment is the formulation of fuzzy rules. The proponent constructed Fuzzy Associative Memory (FAM) matrix for three main blocks of six classifications. The proponent constructed 216 rules as sampled in Figure 6. As mentioned, the factor rates were 0.05, 0.05 and 0.9 for wind energy resource, other wind energy parameters and site-related criteria respectively. As shown in the rule editor, if the wind energy resource is Poor and other wind energy parameters is Poor and the site-related criteria is also Poor, then the wind energy viability assessment is also Poor. This sample rule also applies to other 215 rules with respect to its desired factor rates.

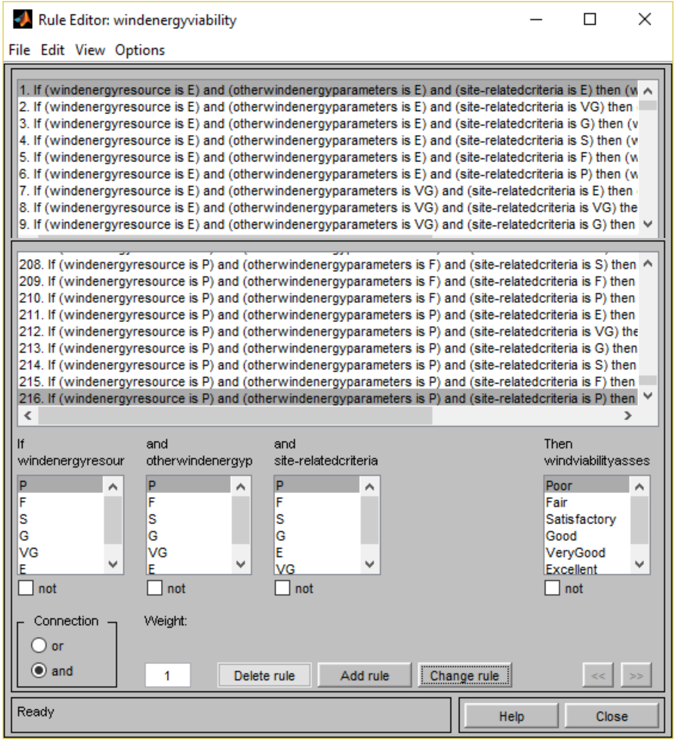

Figure 6: Rule editor for wind energy viability assessment

IV. Simulation Results

The constructed fuzzy control system was simulated and verified to assess its accuracy and robustness for effective wind energy viability assessment of selected sites in Central Luzon. The scoring sheet of selected sites was tabulated in Table 2. The site selection criteria were divided into three main blocks as mentioned earlier and each parameter was rated from 0 to 5 (0 – being the lowest and 5 –being the highest). As shown in the table, Sual Pangasinan and Carranglan Nueva Ecija garnered the highest total score of 4 with linguistic classification of *"Very Good"* while other selected sites garnered an average score of 3, classified as *"Good"*. The survey scores for each parameter were taken from GEC's obtained results. However, the proponent averages the scores of the parameters with respect to each block. The proponent computed for the total score of three main blocks: wind resource density, other wind resource parameters and site-related criteria using factor rates of 5%, 5% and 90% to obtain the total score for each selected site. It was realized that the obtained results of the proponent is paralleled with that of GEC results.

The proponent tested the fuzzy logic control system using the scoring sheet and the results were tabulated in Table 3. The proponent computed for the quantitative site assessment with respect to GEC survey results. Moreover, the crisp output was computed using center of gravity formula using the average weighted mean scores of three main blocks. As shown in the table, it could be observed that Sual Pangasinan and Carranglan Nueva Ecija garnered favourable scores as compared with other selected sites. It is proven that the results obtained using fuzzy logic for wind energy viability analysis for selected sites in Central Luzon is the same with quantitative site assessment results made by GEC without using any computational tool.

Table 2
Scoring Sheet of Selected Sites in Central Luzon

SITE SELECTION CRITERIA	Sampaloc, Rizal	Caliraya, Laguna	Sual, Pangasinan	Pantabangan, Nueva Ecija	Puncan-Digdig, Nueva Ecija (Mountain)	Carranglan, Nueva Ecija (Valley)
1. Wind resource density based on NREL atlas (multiplied by four)	3	2	3	0	5	3
Wind Resource Density Weighted Score	**3**	**2**	**3**	**0**	**5**	**3**
2. On-site wind measurements to confirm wind resource	0	1	0	0	1	1
3. Quality of on-site measured wind speed data	0	0	0	0	0	0
4. Correlation of on-site wind speed data with wind atlas estimates	0	0	0	0	0	0
5. Quality and availability of correlated long-term data	1	0	0	0	0	0
Other Wind Resource Parameters Weighted Score	**0**	**0**	**0**	**0**	**0**	**0**
6. Proximity to transmission lines	2	5	4	4	2	4
7. Upgrades required to existing transmission lines	1	5	5	4	4	4
8. Terrain	4	4	4	2	2	4
9. Accessibility	4	4	4	5	1	5
10. Security	2	2	2	3	3	2
11. Terrain orientation to prevailing wind	4	5	4	2	5	5
12. Landowner concerns	3	1	3	3	3	3
13. Social acceptability	3	1	3	3	3	3
14. Land costs	3	1	3	3	3	3
15. Vegetation over 10m	3	3	3	1	1	3
16. Soil conditions	5	5	5	5	5	5
17. Typhoon passages over provinces (based on PAGASA rankings)	4	4	2	1	1	1
18. Other environmental issues (corrosion, humidity)	4	4	4	4	4	4
19. Insects	3	3	3	3	3	3
20. Cultural or environmental concerns	4	2	4	4	2	4
21. Site capacity, MW	3	3	5	1	5	5
22. Aviation and telecomm conflicts	5	5	5	5	5	5
Site-Related Criteria Weighted Score	**3**	**3**	**4**	**3**	**3**	**4**
TOTAL SCORE	**3**	**3**	**4**	**3**	**3**	**4**
LINGUISTIC CLASSIFICATION	**Good**	**Good**	**Very Good**	**Good**	**Good**	**Very Good**

Table 3
Fuzzy Logic Viability Assessment Of Selected Sites In Central Luzon

Site Location	Renewable Wind Energy Parameters	Average Weighted Mean Scores	Quantitative Site Assessment	Crisp Output (Matlab Fuzzy Logic Toolbox)	Linguistic Classification
Samploc, Rizal	Wind Resource Density	3	3.18	3	Good
	Other Wind Resource Parameters	0.25			
	Site-Related Criteria	3.35			
Caliraya, Laguna	Wind Resource Density	2	3.13	3	Good
	Other Wind Resource Parameters	0.25			
	Site-Related Criteria	3.35			
Sual, Pangasinan	Wind Resource Density	3	3.49	4	Very Good
	Other Wind Resource Parameters	0			
	Site-Related Criteria	3.71			
Pantabangan, Nueva Ecija	Wind Resource Density	0	2.81	3	Good
	Other Wind Resource Parameters	0			
	Site-Related Criteria	3.12			
Puncan-Digdig, Nueva Ecija	Wind Resource Density	5	3.02	3	Good
	Other Wind Resource Parameters	0.25			
	Site-Related Criteria	3.06			
Carranglan, Nueva Ecija	Wind Resource Density	3	3.5	4	Very Good
	Other Wind Resource Parameters	0.25			
	Site-Related Criteria	3.71			

Figure 7 elicits the rule viewer for Puncan-Digdig, Nueva Ecija. The values for three main blocks are: 5, 0.25 and 3.06. The wind viability assessment was "Good" with a crisp value of 3. On the other hand, Figures 8 and 9 elicit the rule viewers for two sites: Sual and Carrangalan who ranked first in the assessment with common crisp values of 4.0 and "Very Good" wind energy viability assessment.

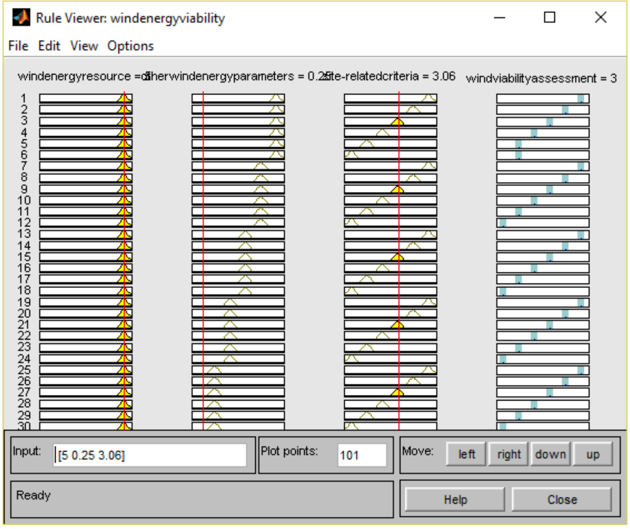

Figure 7: Rule viewer for Puncan-Digdig, Nueva Ecija

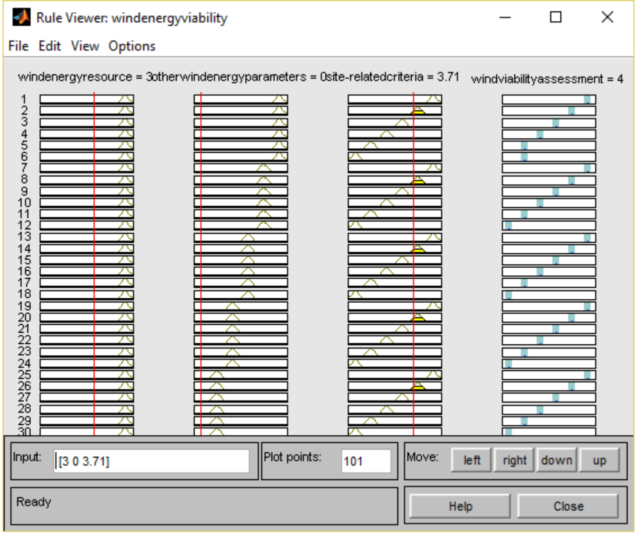

Figure 8: Rule viewer for Sual, Pangasinan

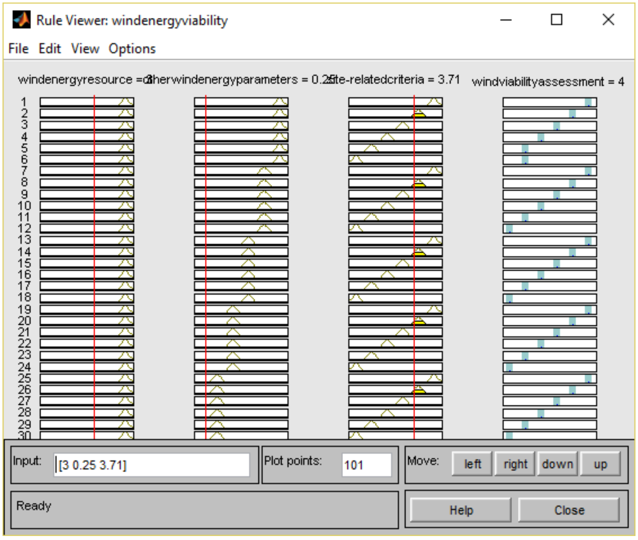

Figure 9: Rule viewer for Carranglan, Nueva Ecija

V. Conclusion and Future Directives

The proponent had developed the fuzzy logic system for wind energy viability assessment for selected sites using Sugeno style of fuzzy inference systems and the results showed that Sual Pangasinan and Carranglan Nueva Ecija with "Very Good" linguistic assessment suits best for possible wind farm development in Central Luzon. In meeting the objectives of the study, the proponent presented relevant literature reviews on wind energy resource in foreign and local context and based from these literature reviews, the proponent were able to develop and illustrate a model of fuzzy logic for representing viability of wind resource. The proponent makes used of triangular membership functions for three main blocks using classifications: Poor, Fair, Satisfactory, Good, Very Good and Excellent. There were 216 fuzzy rules derived using factor rates of 5%, 5% and 90% for wind resource density, other wind resource parameters and site-related criteria respectively. This considers site-related criteria as most important consideration for wind farm development aside from wind density. The proponent tested the fuzzy system using the quantitative assessment made by GEC. The results using fuzzy logic gives same result with that of results obtained by K. Conover. This means that the fuzzy model is accurate and can also be utilized for wind viability assessment of other sites aside from Central Luzon Philippines. The proponent suggests simulation for other possible sites in the Philippine context. Ergo, it would be best if a high-level programming language could be made to facilitate faster and convenient analysis. This is because, in this work, the proponent simulated individually the six selected sites using fuzzy logic matlab toolbox. Other researchers can also explore adding additional parameters, trying other type of membership functions and implementing higher number of rules to facilitate general applications for different site conditions.

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