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Study of Variation of Winds Behavior on Micro Urban Environment with Use of Fuzzy Logic for Wind Power Generation: Case Study in the Cities of Arraial do Cabo and São Pedro da Aldeia, State of Rio de Janeiro, Brazil

Roberto Rosenhaim, Marcos Antonio Crus Moreira, Robson da Cunha, Gerson Gomes Cunha

***Abstract*—**This work provides details on the wind speed behavior within cities of Arraial do Cabo and São Pedro da Aldeia located in the Lakes Region of the State of Rio de Janeiro, Brazil. This region has one of the best potentials for wind power generation. In interurban layer, wind conditions are very complex and depend on physical geography, size and orientation of buildings and constructions around, population density, and land use. In the same context, the fundamental surface parameter that governs the production of flow turbulence in urban canyons is the surface roughness. Such factors can influence the potential for power generation from the wind within the cities. Moreover, the use of wind on a small scale is not fully utilized due to complexity of wind flow measurement inside the cities. It is difficult to accurately predict this type of resource. This study demonstrates how fuzzy logic can facilitate the assessment of the complexity of the wind potential inside the cities. It presents a decision support tool and its ability to deal with inaccurate information using linguistic variables created by the heuristic method. It relies on the already published studies about the variables that influence the wind speed in the urban environment. These variables were turned into the verbal expressions that are used in computer system, which facilitated the establishment of rules for fuzzy inference and integration with an application for smartphones used in the research. In the first part of the study, challenges of the sustainable development which are described are followed by incentive policies to the use of renewable energy in Brazil. The next chapter follows the study area characteristics and the concepts of fuzzy logic. Data were collected in field experiment by using qualitative and quantitative methods for assessment. As a result, a map of the various points is presented within the cities studied with its wind viability evaluated by a system of decision support using the method multivariate classification based on fuzzy logic.

***Keywords*—**Behavior of winds, wind power, fuzzy logic, sustainable development.

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I. Introduction

THE COP - Conference of the Parties to the United Nations Framework Convention on Climate Change, at its 21th edition, played an important role in all countries to encourage the use of renewable energy sources by declining use of fossil fuels in order to meet the reduction targets of the global temperature to 1.5 °C as stated in the agreement cop21 signed on April 22 of 2016.

Renewable energy sources can reduce the dependence of society on fossil fuels, which in turn would also reduce the emission of greenhouse gases on the environment [1].

Economic development is vital for the poorest countries, but the roadmap may not be the same adopted by industrialized countries. There is a major challenge for emerging powers like China, India and Brazil, to maintain its economic growth by eliminating the use of fossil fuels, which worked in the past, but there is now need to establish a new green growth model based on the use clean energy, keeping the progress of these nations [2].

Another important point to be taken into account concerns reduction of the carbon dioxide emission levels in the atmosphere in industrialized countries. It is also necessary to note that the economic and population growth of the last decades have been marked by differences. Although Northern Hemisphere countries have only one-fifth of the world population, they hold four-fifths of the world's income and consume 70% of energy, 75% metals and 85% of global wood production.

According to [2], some factors contributing to the increased use of renewable energy sources are:

1. The energy crisis due to the reduction of world oil reserves;
2. Environmental impacts caused by the use of polluting energy sources;
3. Potential shortage of natural resources and increasing demand for energy supply.

According to the Energy Research Company (EPE) - the Ministry of Mines and Energy of Brazil - demographic, macroeconomic and sectoral assumptions, as well as those relating to energy efficiency and self-production, play a fundamental role in determining the dynamics of consumption electricity, with direct implications on the behavior of various market indicators. In the residential sector, the number of connections to the grid depends on demographic variables such as population, number of households and the number of inhabitants per household; the average consumption per consumer is related with income; namely, with GDP and GDP per capita. These same variables are also important in explaining the other consuming sectors such as commercial grade (trade and services) and other consumption categories. Demand for Brazilian electricity is expected to grow at an average rate in residences as can be seen in Fig. 1 [3], and the production of the other renewable fonts of energy must grow up as can be seen on Table I [3].

Brazil has an important role in the process of international climate agreement signed on April 20, 2016. For its continental size, its population, but mainly by the resources that it has, Brazil may replace the use of fossil fuels within relatively short time period. The country is able to use different sources of energy: wind, solar, bioenergy among others in a diverse array that does not make it dependent on a single resource.

TABLE I
DOMESTIC SUPPLY OF ELECTRICITY

Specification	GWh		Structure (%)	
	2014	2015	2014	2015
Hydro	373439	359743	59.8	58.4
Sugarcane bagasse	32303	34163	5.2	5.5
Wind	12210	21626	2	3.5
Solar	16	59	0.003	0.01
Other renewable	13879	14864	2.2	2.4
Oil	31668	25662	5.1	4.2
Natural gas	81075	79490	13	12.9
Charcoal	18385	19096	2.9	3.1
Nuclear	15378	14734	2.5	2.4
Other nonrenewable	12125	12049	1.9	2
Import	33775	34422	5.4	5.6
Total	624254	615908	100	100
Renewable	465623	464877	74.6	75.5

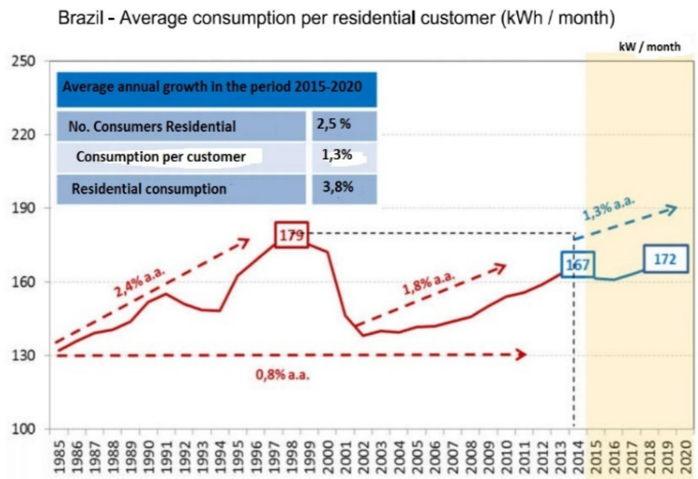

Fig. 1 Projection of electricity demand [3]

In 2015, the amount of wind participants in the Brazilian energy matrix energy was only 3.5%, according to Fig. 2.

As shown in Fig. 3, it is remarkable that the increase in wind power generation has been driven by political incentives as the Proinfa program of the Brazilian government.

The wind in inner cities suffers from various influences of other variables which could affect the correct diagnosis of their actual efficiency in certain regions due to internal features found in urban micro environment also and can be found according to [4]:

1. The wind direction is highly variable in time and space, according to the geographical situation of the site, the surface roughness, relief, vegetation, and the time of year;
2. Knowledge of the prevailing wind direction and average speeds that occur in a site provides important information for positioning windbreaks, guidelines on building stables, distribution of different crops in the field and especially in the positioning and sizing of the towers to the use of this natural energy source.

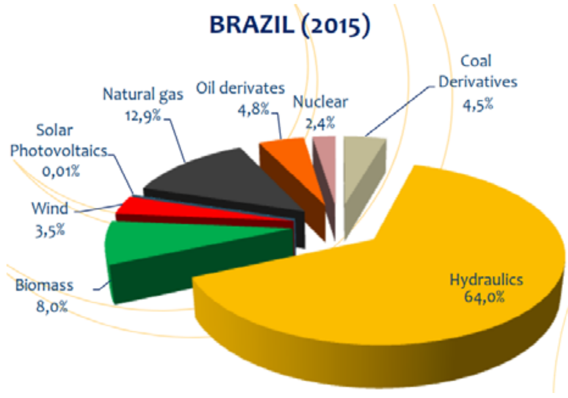

Fig. 2 Brazilian Energy Matrix [3]

Development of wind power in Brazil GWh

2007	2008	2009	2010	2011	2012	2013	2014	2015	Δ 15/14
663	1.183	1.238	2.177	2.705	5.050	6.578	12.210	21.625	77,11%

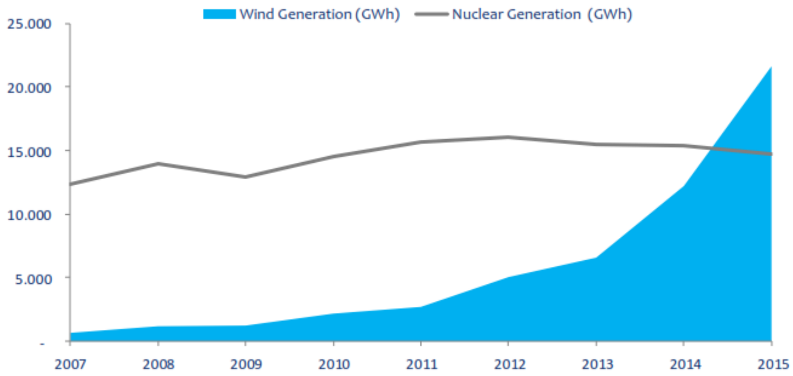

Fig. 3 Development of wind power in Brazil

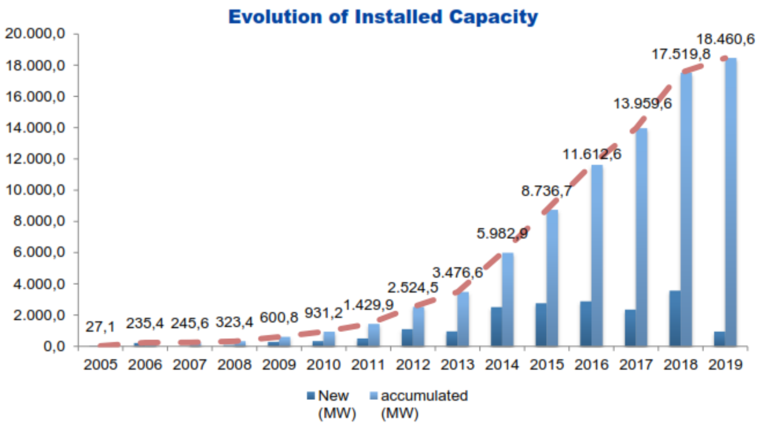

Fig. 4 Evolution of Installed Capacity

II. Brazilian Political Incentive

According to the Brazilian Association of Wind Energy, the first wind turbine to go into commercial operation in South America was the Fernando de Noronha Archipelago (Pernambuco state) in 1992, but it was insufficiently advanced due to the high cost and lack of incentive policies.

Economic development demands the use of more energy as well as the increase in population and improvement of social conditions of the people, and government incentives tend to encourage the use of clean sources [5].

In 2001, the Brazilian government created the PROELICA - Emergency Program for Wind Energy amid energy crisis which was replaced in 2005 by the Incentive Program for Alternative Sources of Electric Energy (Proinfa).

Another important program created by the Brazilian government is ProGD (Distributed Generation Development Program for Energy 15.12.2015), which encourages the generation of energy by consumers themselves based on renewable sources to broaden and deepen the stimulus actions and the generation of energy by the consumers. According to ProGD, some goals are noteworthy: achieve 23% share of renewable energy (in addition to hydropower) in electricity supply, participation of 28% to 33% by 2030 from renewable sources in the energy matrix, reduce emissions greenhouse gases compared to 2005 levels, by 37% by 2025 and by 43% by 2030. As can be seen in Fig. 4 [7] taken from Wind Energy Association Brazilian, a significant increase with respect to capacity and government incentives occurs.

III. Characteristics of the Studied Region

The cities of Arraial do Cabo and São Pedro da Aldeia belong to micro-region of Lagos, usually known as Lake Region of Rio de Janeiro State. They also belong to the middle geographic region of coastal lowland. This region stands out a special microclimate province, due to the lower rainfall, high evapotranspiration, low cloudiness, and wind regime, being dominated by dry vegetation [9].

São Pedro da Aldeia is located at latitude 22º50'21" south

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and longitude 42º06'10" west with a population estimated at 93,659 inhabitants according to Brazilian Institute of Geography and Statistics in 2013, who were delimited to an area of 358.66 km^2.

Arraial do Cabo is located at latitude 22 ° 57'57 " South and longitude 42 ° 01'40" West with a population of approximately 28,866 inhabitants according to Brazilian Institute of Geography and Statistics in 2014.

The presence of a large bay influenced the behavior of the local thermal circulation as a boundary condition in the surface boundary layer [6].

According to [7], the region of Cabo Frio, near Arraial do Cabo and São Pedro da Aldeia, suffers from various influences on the variation of the wind regime of coastal breezes.

Weather features near the southeast coast of Rio de Janeiro show large high-pressure scale system, called anticyclone Subtropical South Atlantic Maritime (asthma), which controls the atmospheric circulation in Cabo Frio. It generates sector Northeast winds and it alternates with the polar anticyclonic systems related to cold fronts passing the coast of Rio de Janeiro, reversing seasonally the wind to southwest, south, and southeast. The result is a predominance of atmospheric circulation of East-Northeast during the summer, fall, and Southwest West during the winter and spring as shown in Fig. 5.

Fig. 5 Dominant synoptic mechanisms in the Brazilian wind regime and Fluminense [10]

According to the Wind Atlas of the State of Rio de Janeiro [8], from the famous windmills of Cabo Frio salt and São Pedro da Aldeia demonstrate the great wind potential in the region and allowed the generation of profit in these small urban centers.

In Fig. 6 from the Wind Atlas of Rio de Janeiro [8], one can see the places with potential for installing wind farms of tens to hundreds of Megawatts scattered among the existing landforms. Among the areas with low cost of interconnection to the electrical system, such as São Pedro da Aldeia (82 GWh) and Arraial do Cabo (44 GWh), two cities are the target of this study, where the annual average wind speeds reach close to 7.0 m/s (50 m high).

IV. Fuzzy Logic

Fuzzy logic includes the inaccurate aspects of logical reasoning used by humans, and has a special feature that involves innovative representation of the handling of inaccurate information, separately in the theory of probability [9]. It provides a method to translate verbal expressions, vague, imprecise, and common features in human communication into numerical values. With this approach, it becomes possible to transfer the human experience for computers, with an immense practical value, including formulation of decision-making strategies.

Fuzzy logic allows you to capture information already perceptible by human beings, behaving as such.

The mathematical approach has many difficulties such as uncertainty parameters and changes due to environmental variations [10], and these problems are found when the need for measurement of wind speeds within the urban environment into account. Its constant variability due to several variables like soil type makes this kind of evaluation difficult.

Instead of using real numbers, the inputs and outputs are described as "fuzyy values" [9]:

IF <variable> = HIGH THEN <output> BIG

where HIGH and BIG are defined by membership functions describing the inaccuracy of such input and output values

Such expressions are built using the heuristic method, which consists in carrying out a task according to the previous experiences. One should note that the fuzzy control strategies are born of experiments experience rather than mathematical models. While the inference based on the *modus ponens* inference rule in classical [11] artificial intelligence systems are based on a symbolic processing, fuzzy inference (approximate reasoning) is based both on symbolic processing as in the processing of meaning.

A. Fuzzy Inference Rules

This study used a free access code tool GNU XFUZZY XML-based [11]. That is JAVA programming language based tool. This software allows integration with other systems.

To design the system was necessary to build sets of variables as recent research [12].

Based on Beaufort scale [13] – shown in Table II – was created fuzzy variable TVelocidadeVentos (wind speed), shown in Table III.

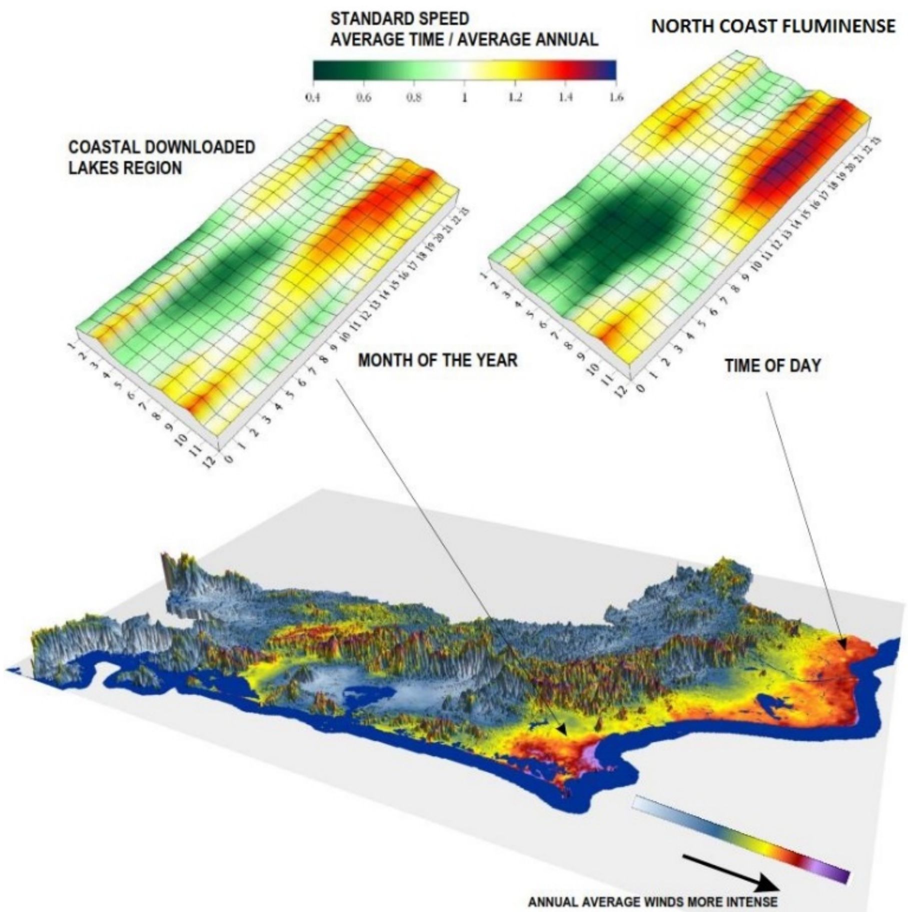

Fig. 6 Intensity distribution of winds and seasonal diurnal regimes on the state of Rio de Janeiro [8]

TABLE II
BEAUFORT SCALE

Degree	Type	m/s	Ground effect
0	calm	<0.3	Smoke rises vertically
1	breeze	0.3 - 1.5	Smoke indicates wind direction
2	light breeze	1.6 - 3.3	The leaves move; mills start working
3	light breeze	3.4 - 5.4	Leaves flutter-and unfurl flags in the wind
4	moderate breeze	5.5 - 7.9	Dust and small raised roles; move the tree branches
5	strong breeze	8 - 10.7	Movement of large branches and small trees
6	fresh wind	10.8 - 13.8	Moving large trees; difficulty walking against the wind

TABLE III
FUZZY TYPE TWINDSPEED [14]

Degree	Type	m/s	*Fuzzy variable*
0	calm	< 0.3	mf0Calmo
1	breeze	0.3 – 1.5	mf1Aragem
2	light breeze	1.6 – 3.3	mf2BrisaLeve
3	light breeze	3.4 – 5.4	mf3BrisaFraca
4	moderate breeze	5.5 – 7.9	mf4BrisaModerada
5	strong breeze	8 – 10.7	mf5BrisaForte
6	fresh wind	10.8 – 13.8	mf6VentoFresco

Table IV [13] shows roughness, and the variable Roughness Land as TRugosidade was establish as presented in Table V.

TABLE IV
ROUGHNESS

z0	Terrain features	Class roughness
1.00	city	
0.80	forest	
0.50	outskirts	3
0.40		
0.30	belts of trees	
0.20	trees and shrubs	
0.10	farm with closed vegetation	2
0.05	farm with open vegetation	
0.03	farm with few trees / buildings	
0.02	areas of airports with buildings and trees	
0.01	areas of airport runways	
0.008	meadow	1
0.005	plowed soil	
0.001	snow	
0.0003	sand	
0.0002		
0.0001	water (lakes, rivers, oceans)	0

Also, the variables were created:

1. TProximidadeConstrucoes: (proximity of buildings)

- mf0Distantes
- mf1Proximas

- mf2MuitoProximas

2. TAlturaConstrucoes: (height of buildings)
- mf0Baixa
- mf1Media
- mf2Altas

3. TAlturaLocalInstalacao : (instalation height)
- mf0Baixa
- mf1Media
- mf2Alta

4. TAdequabilidade: (suitability)
- mf0Baixa
- mf1Media
- mf2Alta

TABLE V
FUZZY TYPE_ROUGHNESS

Class roughness	fuzzy variable
3	mf3AltaCidadeFlorestaSuburbios
2	mf2MediaAreaComArvoresArbustos
1	mf1MediaPastoAeroportosFazenda
0	mf0BaixaAreiaNeveAgua

Fig. 7 Markers in São Pedro da Aldeia, Rio de Janeiro state, Brazil

Systems that use symbolic language end up needing high computational demand, which does not occur with the systems using fuzzy, as demonstrated by the created inference variables. Thereby, the computational analysis process becomes faster and simplified. Fuzzy logic tends to behave as deductive reasoning through the semantic examples that may present conclusions based on already known information. Fuzzy logic allows data collection and thus enables the creation of an intelligent system to support decision based on characteristics of human intelligence.

Fig. 8 Markers in Arraial do Cabo, state of Rio de Janeiro, Brazil

Fig. 9 Window marker fuzzy variables evaluation

V. METHODOLOGY

The methodology relies on a simpler and faster gathering of wind regime corresponding to the data acquired from an anemometer inside urban area. At a second step, the anemometer installation site, which is also a candidate location for turbine placement, is described through the fuzzy sets that express the location adequacy. Finally, rules relating macro and local wind distribution along with location adequacy are established for the fuzzy inference purpose and processed by the fuzzy inference toolkits.

To analyze the data, several points with different characteristics were observed based on the types of variables which are created by using XFUZZY, and such variables were inserted in the smartphone database. The data entry was realized through an application developed for this purpose. This application was developed by using the Android Studio tool in JAVA programming language.

Android has integration with SQLITE [15], which is a lightweight and powerful database, and this database was created directly within the source code itself.

The variables are mapped using XFUZZY [16] tool and are subsequently exported to Java code which facilitated the integration between the Graphical user interface and the generated code.

The developed application consists of a map which uses the Google Maps Android API v2 [15] and it basically consists of a map in which a point is scored. That point just clicks the marker that the user is directed to a screen with questions about the profile found in the current environment. After answering the questionnaire, the user returns to the current map view and can check which the suitability regarding the regime winds of that place based on 87 inference rules created from XFUZZY figures. 86 points, 40 in the city of Arraial do Cabo, and 46 in the city of San Pedro village were mapped. In addition to mapping, the speed of the wind through the automatic weather station in the city of Arraial do Cabo latitude -22.975468º and longitude -42.021450º, altitude 3 m, was harvested in the microenvironment, and the average speed measured in this device was compared with the speeds at every point.

The smartphone application development for this research can be seen in Figs. 8-13.

The application is responsible for taking the latitude and longitude, and writing the data in different tables. It allows the integration with the other software such as online use on websites beyond the export of the latitude and longitude data to software as QGIS to elaborate more complex maps.

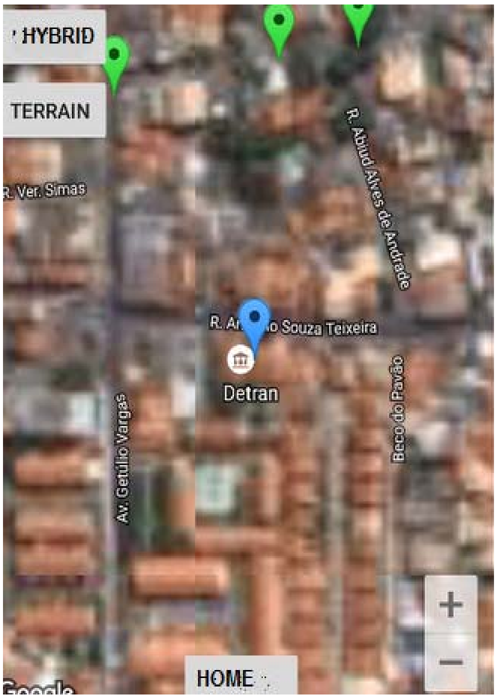

Fig. 10 New marker example

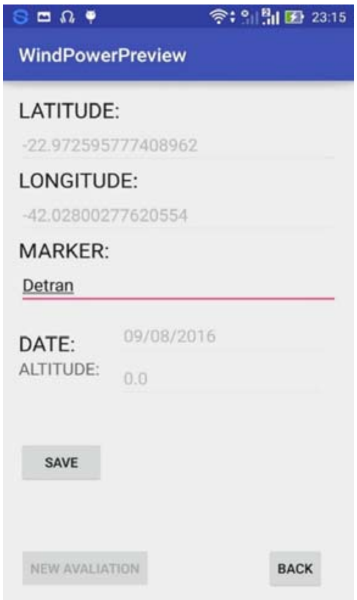

Fig. 11 Marker details

The following data were collected from points:

TABLE VI
ARRAIAL DO CABO MARKERS

id	Marker	latitude	longitude	id	Marker	latitude	longitude
2	Constru_frente_IEAPM	-22.97654999	-42.02220585	22	Praia_grande_restaurante_por_do_sol	-22.97253219	-42.03115102
3	Pousada Santo Anjo	-22.97753991	-42.02254146	23	Hotel_varandas_ao_mar	-22.9719	-42.03088649
4	Esquina_IEAPM	-22.97823751	-42.02260382	24	Praia_grande-condominio_lado_varandas	-22.97137739	-42.03100517
5	Esquina_Ieapm2	-22.97760874	-42.02249553	25	Cobdoninio_praia_grande	-22.97086805	-42.03041073
6	Ponto_Frente_entrada_ieapm	-22.97775073	-42.02315368	26	Padaria_delicias_praia_grande	-22.97291002	-42.02962685
7	Predio_frente_entrada_ieapm	-22.97743866	-42.02324957	27	Pousada_genesis	-22.97250965	-42.02683736
8	Construcao_predio	-22.97681174	-42.02342995	28	Pousada_Pavanelli	-22.97404011	-42.02636529
9	Barzinho_esquina_castelo_branco	-22.97714913	-42.02483844	29	Pracinha_frente_loja_pintando	-22.97467569	-42.02883594
10	Hotel_ressurgencia	-22.97472199	-42.0214089	30	TEAR_pilates	-22.97190988	-42.02788308
11	Posto_salvavidas_frente_ressurgencia	-22.97460932	-42.0211494	31	Esquina_abuid_alves_com_machado_assis	-22.97185832	-42.02758066
12	Residencial_Vila_ElisabetaI	-22.97390769	-42.02149775	32	Bar_amarelinho	-22.97202162	-42.02851105
13	Porto_forno	-22.9702303	-42.01752238	33	Brinquedo_festa	-22.97080261	-42.02785123
14	Praia_anjos_proximo_porto	-22.97031704	-42.01946966	34	Instituto_agape	-22.96846951	-42.02466242
15	Igreja_nossa_senhora_remedios	-22.96931595	-42.01965641	35	Camara_municipal	-22.96938417	-42.02588886
16	Mirante_pontal_atalaia	-22.98124457	-42.02899721	36	Primeira_Igreja_batista	-22.96752089	-42.0267988
17	Recanto_arcanjo_Miguel	-22.97371167	-42.03118019	37	Praca_castelo_branco	-22.9675357	-42.02344302
18	Praia_grande_proximo_guarda	-22.97368327	-42.0315557	38	Edificio_prainha	-22.96087724	-42.02497859
19	Praia_grande_associacao_pescadores	-22.9730977	-42.03142561	40	Quisoque_prainha_vasco	-22.96105012	-42.02283282
20	Praia_grande_restaurante_deck_praia	-22.97331193	-42.03167103	41	Pousada_thetis	-22.95949173	-42.02556565
21	Praia_grande_quiosque_do_max	-22.97267789	-42.03150876	42	Entrada_condominio_vilage_pontal	-22.95482356	-42.03178369

TABLE VII
ARRAIAL DO CABO WIND

_id	speed	markerid	date	_id	speed	markerid	date	_id	speed	markerid	date
1	2.0	2	02/07/2016	15	4.8	17	04/07/2016	29	1.3	33	04/07/2016
2	1.2	3	02/07/2016	16	1.2	18	04/07/2016	30	0.8	34	04/07/2016
3	2.5	5	02/07/2016	17	1.9	19	04/07/2016	31	2.2	35	04/07/2016
4	2.7	6	02/07/2016	18	2.6	21	04/07/2016	32	2.3	36	04/07/2016
5	3.8	7	02/07/2016	19	0.7	22	04/07/2016	33	1.6	37	04/07/2016
6	2.6	8	02/07/2016	20	2.3	24	04/07/2016	34	2.0	38	04/07/2016
7	1.8	9	02/07/2016	21	2.6	25	04/07/2016	35	3.0	40	04/07/2016
8	3.1	10	02/07/2016	22	2.3	26	04/07/2016	36	1.8	41	04/07/2016
9	4.4	11	02/07/2016	23	2.4	27	04/07/2016	37	1.9	42	04/07/2016
10	3.6	12	02/07/2016	24	2.1	28	04/07/2016				
11	1.9	13	02/07/2016	25	1.0	29	04/07/2016				
12	2.5	14	02/07/2016	26	1.3	30	04/07/2016				
13	1.4	15	02/07/2016	27	0.1	31	04/07/2016				
14	2.3	16	02/07/2016	28	1.3	32	04/07/2016				

TABLE VIII
ARRAIAL DO CABO BUILDING PROXIMITY AND HEIGHT OF BUILDINGS AROUND

_id	markerid	proximity	height	_id	markerid	proximity	height	_id	markerid	proximity	height
1	2	NEAR	MODERATE	16	17	VERY CLOSE	LOW	31	32	VERY CLOSE	LOW
2	3	FAR	LOW	17	18	FAR	MODERATE	32	33	NEAR	MODERATE
3	4	VERY CLOSE	LOW	18	19	FAR	LOW	33	34	FAR	LOW
4	5	VERY CLOSE	LOW	19	20	FAR	HIGH	34	35	FAR	LOW
5	6	FAR	LOW	20	21	FAR	LOW	35	36	NEAR	LOW
6	7	FAR	LOW	21	22	VERY CLOSE	HIGH	36	37	FAR	MODERATE
7	8	NEAR	LOW	22	23	VERY CLOSE	HIGH	37	38	VERY CLOSE	LOW
8	9	NEAR	HIGH	23	24	NEAR	HIGH	38	40	VERY CLOSE	MODERATE
9	10	FAR	MODERATE	24	25	NEAR	MODERATE	39	41	FAR	HIGH
10	11	FAR	LOW	25	26	VERY CLOSE	MODERATE	40	42	FAR	LOW
11	12	FAR	LOW	26	27	FAR	MODERATE				
12	13	FAR	LOW	27	28	NEAR	LOW				
13	14	FAR	LOW	28	29	NEAR	LOW				
14	15	FAR	LOW	29	30	NEAR	LOW				
15	16	FAR	LOW	30	31	NEAR	MODERATE				

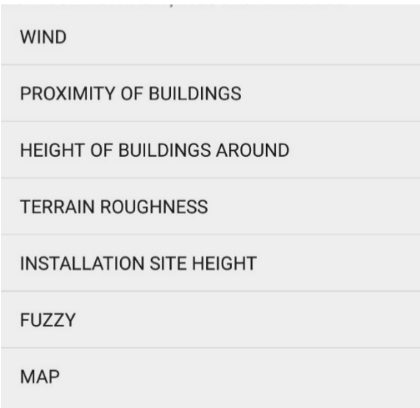

Fig. 12 List with fuzzy linguistic variables

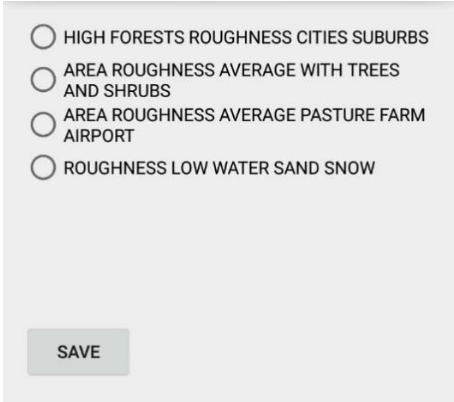

Fig. 13 Marker roughness evaluation

TABLE IX
ARRAIAL DO CABO HEIGHT OF TERRAIN ROUGHNESS

_id	markerid	Roughness
1	2	High Forests Roughness Cities Suburbs
2	3	High Forests Roughness Cities Suburbs
3	4	High Forests Roughness Cities Suburbs
4	5	High Forests Roughness Cities Suburbs
5	6	High Forests Roughness Cities Suburbs
6	7	High Forests Roughness Cities Suburbs
7	8	High Forests Roughness Cities Suburbs
8	9	High Forests Roughness Cities Suburbs
9	10	High Forests Roughness Cities Suburbs
10	11	Roughness Low Water Sand Snow
11	12	High Forests Roughness Cities Suburbs
12	13	Roughness Low Water Sand Snow
13	14	Roughness Low Water Sand Snow
14	15	High Forests Roughness Cities Suburbs
15	16	Area Roughness Average With Trees And Shrubs
16	17	High Forests Roughness Cities Suburbs
17	18	Area Roughness Average Pasture Farm Airport
18	19	High Forests Roughness Cities Suburbs
19	20	Roughness Low Water Sand Snow
20	21	High Forests Roughness Cities Suburbs
21	22	High Forests Roughness Cities Suburbs
22	23	High Forests Roughness Cities Suburbs
23	24	High Forests Roughness Cities Suburbs
24	25	High Forests Roughness Cities Suburbs
25	26	High Forests Roughness Cities Suburbs
26	27	High Forests Roughness Cities Suburbs
27	28	High Forests Roughness Cities Suburbs
28	29	Area Roughness Average With Trees And Shrubs
29	30	Area Roughness Average With Trees And Shrubs
30	31	Area Roughness Average With Trees And Shrubs
31	32	High Forests Roughness Cities Suburbs
32	33	High Forests Roughness Cities Suburbs
33	34	High Forests Roughness Cities Suburbs
34	35	High Forests Roughness Cities Suburbs
35	36	High Forests Roughness Cities Suburbs
36	37	High Forests Roughness Cities Suburbs
37	38	High Forests Roughness Cities Suburbs
38	40	Roughness Low Water Sand Snow
39	41	Area Roughness Average Pasture Farm Airport
40	42	Area Roughness Average With Trees And Shrubs

TABLE X
ARRAIAL DO CABO INSTALLATION SITE HEIGHT

_id	markerid	height	_id	markerid	height
1	2	HIGH	21	22	HIGH
2	3	HIGH	22	23	HIGH
3	4	LOW	23	24	MODERATE
4	5	LOW	24	25	MODERATE
5	6	LOW	25	26	HIGH
6	7	HIGH	26	27	LOW
7	8	HIGH	27	28	MODERATE
8	9	MODERATE	28	29	LOW
9	10	MODERATE	29	30	LOW
10	11	MODERATE	30	31	LOW
11	12	MODERATE	31	32	MODERATE
12	13	LOW	32	33	LOW
13	14	LOW	33	34	MODERATE
14	15	MODERATE	34	35	MODERATE
15	16	HIGH	35	36	HIGH
16	17	MODERATE	36	37	LOW
17	18	MODERATE	37	38	HIGH
18	19	MODERATE	38	40	LOW
19	20	LOW	39	41	LOW
20	21	MODERATE	40	42	LOW

TABLE XI
ARRAIAL DO CABO FUZZY

_id	markerid	fuzzy_evaluation	_id	markerid	fuzzy_evaluation
2	2	Low Viability	22	22	Low Viability
3	3	Low Viability	23	23	Not Yet Done
4	4	Not Yet Done	24	24	Low Viability
5	5	Low Viability	25	25	Low Viability
6	6	High Viability	26	26	Low Viability
7	7	Low Viability	27	27	High Viability
8	8	Low Viability	28	28	Low Viability
9	9	Low Viability	29	29	Low Viability
10	10	Low Viability	30	30	Low Viability
11	11	Average Viability	31	31	Low Viability
12	12	Low Viability	32	32	Low Viability
13	13	Average Viability	33	33	Low Viability
14	14	Average Viability	34	34	Low Viability
15	15	Low Viability	35	35	Low Viability
16	16	Low Viability	36	36	Low Viability
17	17	Low Viability	37	37	High Viability
18	18	Low Viability	38	38	Low Viability
19	19	Low Viability	40	40	Low Viability
20	20	Not Yet Done	41	41	Average Viability
21	21	LOW VIABILITY	42	42	High Viability

TABLE XII
SÃO PEDRO DA ALDEIA MARKERS

id	marker	latitude	longitude	id	marker	latitude	longitude
43	Garagem_ampla	-22.83152944	-42.09818244	67	Pastel	-22.84027345	-42.10294906
44	Jardim_escola_coracao_sabido	-22.83129367	-42.09916178	68	Hospital_missao	-22.84069058	-42.10359447
45	Predio_esquina_vila_militar	-22.83070686	-42.10014246	69	Pousada_vilaMares	-22.84481981	-42.10401189
46	Escola_estadual	-22.8300978	-42.09989201	70	Prefeitura	-22.84096341	-42.10109733
47	Casa_421	-22.82810684	-42.09987257	71	Forum	-22.84038221	-42.10081268
48	Serralheria_caires	-22.82909475	-42.10130285	72	Sport_clube_SaoPedro	-22.84072209	-42.09929589
49	Praca_estacao	-22.83075692	-42.10226275	73	Academia_CTLA	-22.83922196	-42.10023098
50	Segunda_igreja_batista	-22.82966735	-42.10443735	74	Razao_contabilidade	-22.83847729	-42.10091226
51	Silver_hawk_cross_fit	-22.83083387	-42.10707061	75	Teatro_municipal	-22.8395294	-42.09754843
52	Escola_almirante_carneiro_ribeiro	-22.82778979	-42.11217385	76	Bar_refugio	-22.84256766	-42.09716454
53	Terreno_frente_posto	-22.82690384	-42.11408392	77	Espaco_atelie21	-22.84142905	-42.09428854
54	Fisio_trauma	-22.8316172	-42.10450742	78	Capela_saoFranciscoAssis	-22.84838659	-42.09729396
55	Capoteiro_proximo_academia_artes_marciais	-22.83333249	-42.10163847	79	Grupo_espiritaFranciscoAssis	-22.8483489	-42.10212462
56	Travessazproximo_garagem_ampla	-22.83243298	-42.09860455	80	Capela_SaoPedro	-22.84945253	-42.10352808
57	Posto_Puma	-22.83330375	-42.09858209	81	Super_epa	-22.85128469	-42.10304059
59	Mercado_peixe	-22.83426351	-42.10106112	82	Praca_possoFundo	-22.86034718	-42.10805599
60	Tere_frutas	-22.83530453	-42.10058469	83	Creche_tiaMarcia	-22.86317304	-42.10938904
61	Mercado_economico	-22.83522821	-42.1016378	84	Restaurante_delicias_lagoa	-22.86263487	-42.11374428
62	Caixa_economica	-22.83567718	-42.10271806	85	Pousada	-22.8636006	-42.11650092
63	Praca_centro	-22.83518464	-42.10438941	86	Proximo_pousada_xodo_praia	-22.87315653	-42.11537708
64	Rua_da_parra	-22.83699907	-42.10327193	87	Pousada_xodo_praia	-22.87287944	-42.11614318
65	Igreja_matriz	-22.83868895	-42.10285384	88	Esquina_robertoMarinho	-22.87639822	-42.1190621
66	Beco_das_massas	-22.8397973	-42.10297253	89	Predio_construcao	-22.83539538	-42.09468585

TABLE XIII
SÃO PEDRO DA ALDEIA WIND

_id	markerid	speed	date	_id	markerid	speed	date
38	43	2.0	07/07/2016	61	67	2.3	07/07/2016
39	44	1.5	07/07/2016	62	68	2.3	07/07/2016
40	45	2.3	07/07/2016	63	69	1.5	07/07/2016
41	46	2.5	07/07/2016	64	70	2.3	07/07/2016
42	47	2.0	07/07/2016	65	71	2.5	07/07/2016
43	48	2.3	07/07/2016	66	72	2.5	07/07/2016
44	49	2.0	07/07/2016	67	73	3.0	07/07/2016
45	50	3.5	07/07/2016	68	74	1.3	07/07/2016
46	51	3.5	07/07/2016	69	75	2.5	07/07/2016
47	52	4.0	07/07/2016	70	76	2.4	07/07/2016
48	53	4.5	07/07/2016	71	77	3.3	07/07/2016
49	54	2.8	07/07/2016	72	78	3.0	07/07/2016
50	55	2.3	07/07/2016	73	79	1.2	07/07/2016
51	56	1.8	07/07/2016	74	80	2.3	07/07/2016
52	57	2.0	07/07/2016	75	81	3.4	07/07/2016
53	59	1.5	07/07/2016	76	82	2.5	07/07/2016
54	60	1.5	07/07/2016	77	83	1.4	07/07/2016
55	61	1.5	07/07/2016	78	84	2.8	07/07/2016
56	62	1.0	07/07/2016	79	85	4.0	07/07/2016
57	63	6.0	07/07/2016	80	86	1.3	07/07/2016
58	64	0.8	07/07/2016	81	87	5.3	07/07/2016
59	65	2.7	07/07/2016	82	88	1.9	07/07/2016
60	66	1.7	07/07/2016	83	89	4.6	07/07/2016

TABLE XIV
SÃO PEDRO DA ALDEIA BUILDING PROXIMITY DND HEIGHT OF BUILDINGS AROUND

_id	markerid	proximity	height	_id	markerid	proximity	height
41	43	FAR	LOW	64	67	NEAR	LOW
42	44	NEAR	MODERATE	65	68	NEAR	LOW
43	45	NEAR	LOW	66	69	VERY CLOSE	MODERATE
44	46	FAR	LOW	67	70	NEAR	LOW
45	47	NEAR	LOW	68	71	FAR	LOW
46	48	NEAR	LOW	69	72	FAR	LOW
47	49	FAR	LOW	70	73	NEAR	MODERATE
48	50	FAR	LOW	71	74	VERY CLOSE	LOW
49	51	NEAR	LOW	72	75	FAR	LOW
50	52	NEAR	LOW	73	76	FAR	MODERATE
51	53	FAR	LOW	74	77	FAR	LOW
52	54	NEAR	MODERATE	75	78	FAR	LOW
53	55	VERY CLOSE	MODERATE	76	79	VERY CLOSE	MODERATE
54	56	NEAR	LOW	77	80	FAR	LOW
55	57	NEAR	MODERATE	78	81	NEAR	HIGH
56	59	NEAR	HIGH	79	82	FAR	LOW
57	60	FAR	LOW	80	83	FAR	LOW
58	61	NEAR	MODERATE	81	84	NEAR	LOW
59	62	VERY CLOSE	HIGH	82	85	FAR	LOW
60	63	FAR	LOW	83	86	NEAR	LOW
61	64	VERY CLOSE	MODERATE	84	87	VERY CLOSE	LOW
62	65	NEAR	LOW	85	88	FAR	LOW
63	66	VERY CLOSE	LOW				

TABLE XV
SÃO PEDRO DA ALDEIA HEIGHT OF TERRAIN ROUGHNESS

_id	markerid	roughness	_id	markerid	roughness
41	43	Roughness Low Water Sand Snow	64	67	High Forests Roughness Cities Suburbs
42	44	Roughness Low Water Sand Snow	65	68	High Forests Roughness Cities Suburbs
43	45	Roughness Low Water Sand Snow	66	69	Roughness Low Water Sand Snow
44	46	Roughness Low Water Sand Snow	67	70	High Forests Roughness Cities Suburbs
45	47	High Forests Roughness Cities Suburbs	68	71	High Forests Roughness Cities Suburbs
46	48	High Forests Roughness Cities Suburbs	69	72	High Forests Roughness Cities Suburbs
47	49	Area Roughness Average Pasture Farm Airport	70	73	Area Roughness Average With Trees And Shrubs
48	50	High Forests Roughness Cities Suburbs	71	74	High Forests Roughness Cities Suburbs
49	51	Roughness Low Water Sand Snow	72	75	Area Roughness Average Pasture Farm Airport
50	52	High Forests Roughness Cities Suburbs	73	76	Area Roughness Average Pasture Farm Airport
51	53	Roughness Low Water Sand Snow	74	77	High Forests Roughness Cities Suburbs
52	54	High Forests Roughness Cities Suburbs	75	78	Area Roughness Average Pasture Farm Airport
53	55	High Forests Roughness Cities Suburbs	76	79	High Forests Roughness Cities Suburbs
54	56	Roughness Low Water Sand Snow	77	80	High Forests Roughness Cities Suburbs
55	57	High Forests Roughness Cities Suburbs	78	81	Roughness Low Water Sand Snow
56	59	High Forests Roughness Cities Suburbs	79	82	Area Roughness Average Pasture Farm Airport
57	60	High Forests Roughness Cities Suburbs	80	83	Area Roughness Average Pasture Farm Airport
58	61	High Forests Roughness Cities Suburbs	81	84	Roughness Low Water Sand Snow
59	62	High Forests Roughness Cities Suburbs	82	85	Area Roughness Average Pasture Farm Airport
60	63	Roughness Low Water Sand Snow	83	86	Roughness Low Water Sand Snow
61	64	High Forests Roughness Cities Suburbs	84	87	High Forests Roughness Cities Suburbs
62	65	High Forests Roughness Cities Suburbs	85	88	Area Roughness Average With Trees And Shrubs
63	66	Area Roughness Average With Trees And Shrubs	86	89	High Forests Roughness Cities Suburbs

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TABLE XVI
SÃO PEDRO DA ALDEIA INSTALLATION SITE HEIGHT

_id	markerid	height	_id	markerid	height
41	43	LOW	64	68	LOW
42	44	MODERATE	65	69	MODERATE
43	45	HIGH	66	70	LOW
44	46	LOW	67	71	MODERATE
45	47	LOW	68	72	LOW
46	48	LOW	69	73	LOW
47	49	LOW	70	74	MODERATE
48	50	HIGH	71	75	MODERATE
49	51	LOW	72	76	LOW
50	52	MODERATE	73	77	LOW
51	53	LOW	74	78	MODERATE
52	54	HIGH	75	79	HIGH
53	55	MODERATE	76	80	LOW
54	56	LOW	77	81	HIGH
55	57	LOW	78	82	LOW
56	59	LOW	79	83	LOW
57	61	MODERATE	80	84	LOW
58	62	HIGH	81	85	HIGH
59	63	LOW	82	86	LOW
60	64	MODERATE	83	87	MODERATE
61	65	LOW	84	88	LOW
62	66	LOW	85	89	HIGH
63	67	MODERATE			

TABLE XVII
SÃO PEDRO DA ALDEIA FUZZY

_id	markerid	fuzzy_evaluation	_id	markerid	fuzzy_evaluation
43	43	AVERAGE VIABILITY	68	68	LOW VIABILITY
44	44	LOW VIABILITY	69	69	LOW VIABILITY
45	45	LOW VIABILITY	70	70	LOW VIABILITY
46	46	AVERAGE VIABILITY	71	71	LOW VIABILITY
47	47	LOW VIABILITY	72	72	HIGH VIABILITY
48	48	LOW VIABILITY	73	73	LOW VIABILITY
49	49	AVERAGE VIABILITY	74	74	LOW VIABILITY
50	50	LOW VIABILITY	75	75	LOW VIABILITY
51	51	AVERAGE VIABILITY	76	76	LOW VIABILITY
52	52	LOW VIABILITY	77	77	HIGH VIABILITY
53	53	AVERAGE VIABILITY	78	78	LOW VIABILITY
54	54	LOW VIABILITY	79	79	LOW VIABILITY
55	55	LOW VIABILITY	80	80	HIGH VIABILITY
56	56	HIGH VIABILITY	81	81	LOW VIABILITY
57	57	LOW VIABILITY	82	82	AVERAGE VIABILITY
59	59	LOW VIABILITY	83	83	HIGH VIABILITY
61	61	LOW VIABILITY	84	84	HIGH VIABILITY
62	62	LOW VIABILITY	85	85	LOW VIABILITY
63	63	LOW VIABILITY	86	86	HIGH VIABILITY
64	64	LOW VIABILITY	87	87	LOW VIABILITY
65	65	LOW VIABILITY	88	88	HIGH VIABILITY
66	66	LOW VIABILITY	89	89	LOW VIABILITY
67	67	LOW VIABILITY			

VI. CONCLUSION

The work from Mamdani and Assilian [17] was the model of inferences used for the measurement of points which best suited the processing power of the smartphone, and this model uses the union and intersection operations between sets just like Zadeh [18].

All variables used in the fuzzy system, as well as its evaluation algorithm based on studies of the other authors as cited throughout the text. We came to the maps of Figs. 7 and 8, which show dots in different colors. From Tables XVIII and XX, it can be see that there are many variations with the points, which would have better use of the wind power. Tables

XVIII, XIX and Fig. 14 for Arraial do Cabo and Tables XX, XXI and Fig. 14 for São Pedro da Aldeia and Fig. 15 shows all the best points in this Region.

Most points had in common distant buildings and low installation site with the exception of point with id 79 in São Pedro da Aldeia, but still it is difficult to know if the roughness or proximity of buildings among the other variables has influenced really in deciding on the places with better wind suitability.

The smartphone application, which was create for the integration of survey data with the use of fuzzy algorithm to support decision, is presented as a tool that facilitates and streamlines the process of local assessment, which is conducive to the installation of vertical axis wind towers for better wind exploitation.

Features such as the use of fuzzy linguistic variables that uses our common language and the use of new technologies can contribute to industry and households in order to invest in equipment for energy production through renewable energy sources, with the best return on investment. This can contribute to global targets reducing carbon dioxide in the atmosphere. Thus, developing countries may continue to grow, maintaining a healthy planet for the future generations.

New variables such as temperature, precipitation and air density, which might have influence on the result of the algorithm presenting new results that could be studied. This opens room for further discussions and future studies may be proposed.

TABLE XVIII
MARKERS WITH HIGH AVAILABILITY ARRAIAL DO CABO

idmarker	LAT	long	installation height	wind speed
6	-22.977751	-42.023154	LOW	2.7
27	-22.97251	-42.026837	LOW	2.4
37	-22.967536	-42.023443	LOW	1.6
42	-22.954824	-42.031784	LOW	1.9

TABLE XIX
MARKERS WITH HIGH AVAILABILITY ARRAIAL DO CABO

idmarker	roughness	height of buildings around	buildings proximity
6	High Forests Roughness Cities Suburbs	LOW	FAR
27	High Forests Roughness Cities Suburbs	LOW	FAR
37	High Forests Roughness Cities Suburbs	LOW	FAR
42	Area Roughness Average With Trees And Shrubs	LOW	FAR

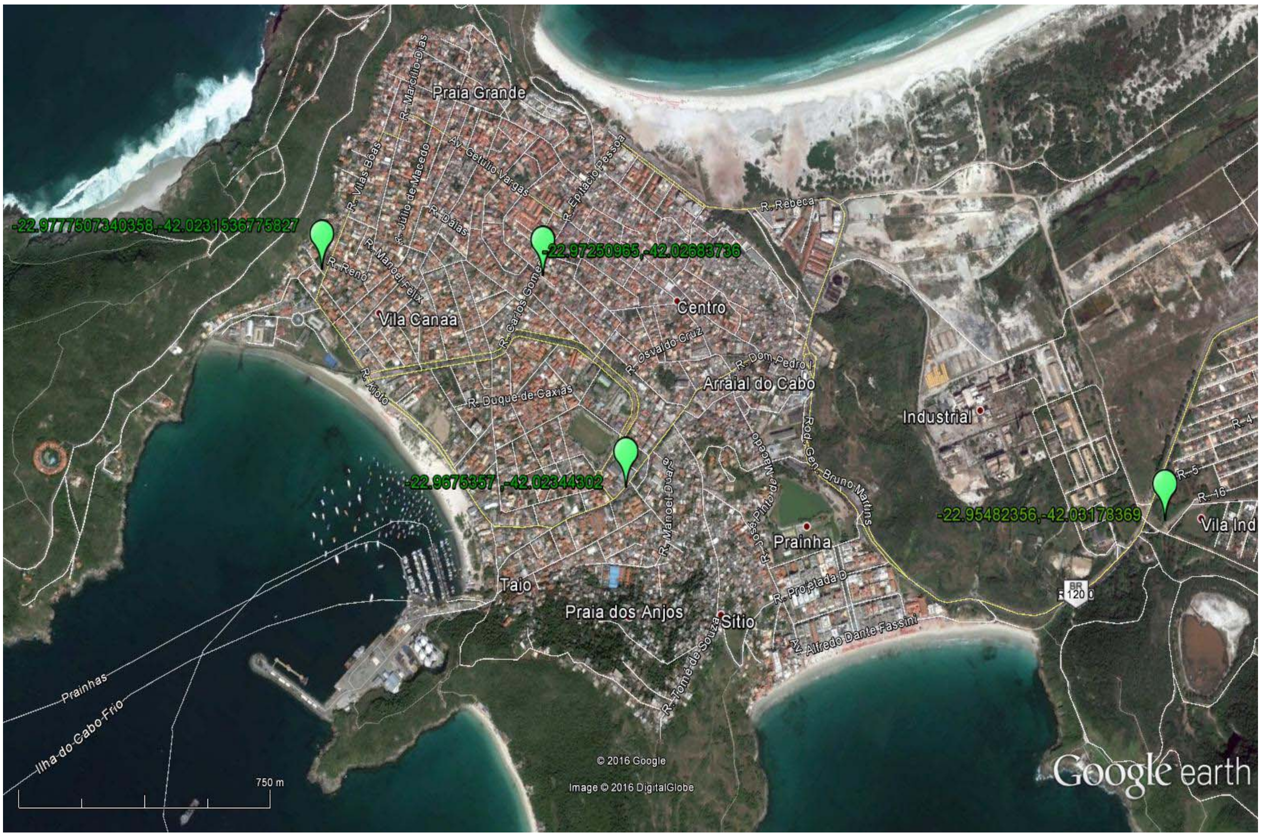

Fig. 14 Markers with high availability Arraial do Cabo

Fig. 15 Markers with high availability São Pedro da Aldeia

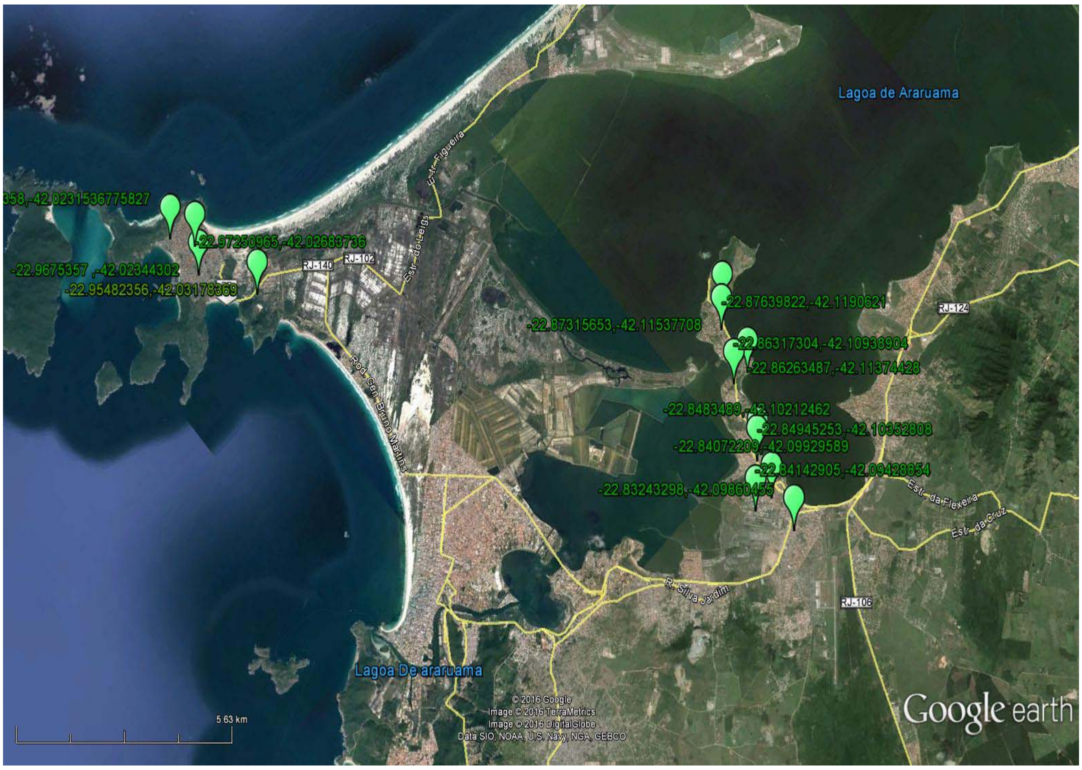

Fig. 16 Markers with high availability

TABLE XX
MARKERS WITH HIGH AVAILABILITY SÃO PEDRO DA ALDEIA

idmarker	LAT	long	instalation height	windspeed
56	-22.832433	-42.098605	LOW	1.8
72	-22.840722	-42.099296	LOW	2.5
77	-22.841429	-42.094289	LOW	3.3
79	-22.848349	-42.102125	HIGH	1.2
80	-22.849453	-42.103528	LOW	2.3
83	-22.863173	-42.109389	LOW	1.4
84	-22.862635	-42.113744	LOW	2.8
86	-22.873157	-42.115377	LOW	1.3
88	-22.876398	-42.119062	LOW	1.9

TABLE XXI
MARKERS WITH HIGH AVAILABILITY SÃO PEDRO DA ALDEIA

idmarker	rougnhess	height of buildings around	buildings proximity
56	Roughness Low Water Sand Snow	LOW	NEAR
72	High Forests Roughness Cities Suburbs	LOW	FAR
77	High Forests Roughness Cities Suburbs	LOW	FAR
79	High Forests Roughness Cities Suburbs	MODERATE	VERY CLOSE
80	High Forests Roughness Cities Suburbs	LOW	FAR
83	Area Roughness Average Pasture Farm Airport	LOW	FAR
84	Roughness Low Water Sand Snow	LOW	NEAR
86	Roughness Low Water Sand Snow	LOW	NEAR
88	Area Roughness Average With Trees And Shrubs	LOW	FAR

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