

PRELIMINARY ANALYSIS OF WIND PARAMETERS AT THE PLANNED CONSTRUCTION SITES OF WIND GENERATORS

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ABSTRACT

To choose optimal place for wind turbine, you need to know two basic parameters:

1. V_{average} – the average wind throughout the year (or during the season when more electricity is needed). The total amount of kilowatt hours of electricity you will get, depends on this parameter.
2. V_{max} – the maximum possible dangerous gust of wind during a storm. The required strength depends on this parameter and hence the cost of construction.

In order to evaluate the place itself, it is possible to combine these two parameters to only one physical parameter: V_{Bojat} – the average wind speed which is devaluated by hurricanes.

In this article, it is called: “Bojatspeed”:
$$V_{\text{Bojat}} = \frac{V_{\text{average}}^3}{V_{\text{max}}^2}.$$

Measurements for V_{average} must be done for at least a year, but for V_{max} for at least ten years. They are obligatory before any decision about construction of wind turbine. And not generally in the country, but exactly in the particular place. A system of two devices for such measurements is described in this article: anemometer and brazmometer. Both are made in Latvia. They are purely mechanical and include no electronics – that is why they do not require battery or any service during many years.

Keywords

return on investment; wind energy conversion; wind profile; anemometer; brazmometer.

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1. INTRODUCTION

To understand why the long-term preliminary measurements of wind are so important, let us consider situation in Germany.

1.1. Problem

Germany has built thousands of wind turbines in places where there is no good wind. Some locations like Bavaria are between the mountains far away from sea, and it was obvious that the average wind is negligible there. However, when you drive on the highway, you can see many wind turbines installed on the left and right. And most of the time, they don't rotate. It looks like the wind turbines were built without preliminary wind measurements. Constructors do not care; they build not where there is the wind but where there is government money.

The cost of government subsidies currently amounts to 27 billion Euro per annum and is transferred to the consumer. In the past 10 years, the price of electric power has already doubled. The consequence is a gigantic redistribution of wealth from population to a few subsidy receivers.

Obviously, such an outrage cannot continue indefinitely. Recently, under pressure from some political parties, the wind industry moves away from governments guaranteeing generous fixed subsidised tariffs for power. This leads to wind parks insolvency. See for example [2], [5]. This is about billions of euro in losses for investors.

In Latvia, we also pay so called "OIK" tax to support wind turbines. (In Latvian: "OIK" – *obligātā iepirkuma komponente* – mandatory procurement component). This means that, wind turbines installed in not proper places make economical damage also in Latvia.

But the wind energy itself is not guilty in people grid and misunderstanding. The wind blows in Latvia entire year and so it is logical to use it. But the locations for wind turbine must be chosen correctly; otherwise, it brings only losses. Also type of wind turbine should be used correctly.

That is why it is necessary to analyze the wind few years before the wind turbine construction.

1.2. The idea of "Bojat" wind speed

The two parameters mentioned above in the abstract have different effect on the choice of a wind turbine model.

It is shown in this article that these two parameters can be reduced to only one physical parameter: average speed, discounted by hurricanes (let us call it the Bojat speed. This word is firstly introduced here, and comes from Latvian "Bojat" – Spoiled). This parameter is introduced here for the first time in order to help solve the question of the economic feasibility of building a wind generator in a given

location. For the final solution of the issue from an economic point of view, it is necessary to take into account other, not only physical, but but purely economic parameters: the price of electricity in the country, the demand for electricity in a given settlement, the average rate of return on investments in the world, the level of inflation, reliability of the equipment supplier, etc. Such an abundance of necessary information confuses decision-makers. Therefore, people will always strive to reduce the number of parameters. Such reduction is achievable if you choose the right mathematical combination of them.

This generalized one-dimensional valuation is good for answering the question: “Yes” or “No”? But once the decision has been made: “Yes, we will install a wind turbine here”, then all the parameters involved must be analyzed separately again in order to select a specific wind turbine model.

It is a big mistake to install only the same wind turbine model with three blades on one leg everywhere. The monopoly of one design is the second reason for the economic disaster of the wind power industry. Of course, in places with strong winds one model will be suitable, and in places with weak winds a completely different model will be suitable. But this will be subject of other publications. This article is focused only on the question: how to rank different locations according to their suitability independently of model.

2. MEASUREMENT DEVICES DEVELOPED BY THE AUTHOR

The author has created prototypes of two instruments for measuring these parameters: a long-acting anemometer and a brazmometer. Please see the Figure 1 and 2. The name “Brazmometer” is firstly introduced here. This word comes from Latvian *brāzma* – gust. Both devices can be suspended on a one rope between two trees or be installed on 10 meter mast. The devices are purely mechanical and are very cheap to manufacture, which makes the experiments described below relatively cheap.

It makes no big sense to buy one expensive electronic anemometer, which records the strength of the wind every second and transmits data via satellite communication to a computer because it functions only at one location. It is much better for the same money to install dozens of cheap mechanical devices at different locations. Because for decision about installation of wind turbine no one needs the wind speed report every second. In reality, only two integral figures are needed after many years of observation: the average wind speed and the maximum possible wind speed. But these two numbers must be measured for many locations to choose between them.

A consumer, for example, a farmer who is considering construction of wind turbine in his field, will be able to install several such measurement devices at different ends of his field, and after many years of observation, he will be surprised to find that at some location the average wind blows stronger, and dangerous gusts

of wind are weaker than elsewhere in the same field. That will give him the opportunity to get benefits from the correct placement of the wind turbine.

2.1. Long-term anemometer – device to measure average wind's speed during very long period (for example 10 years).

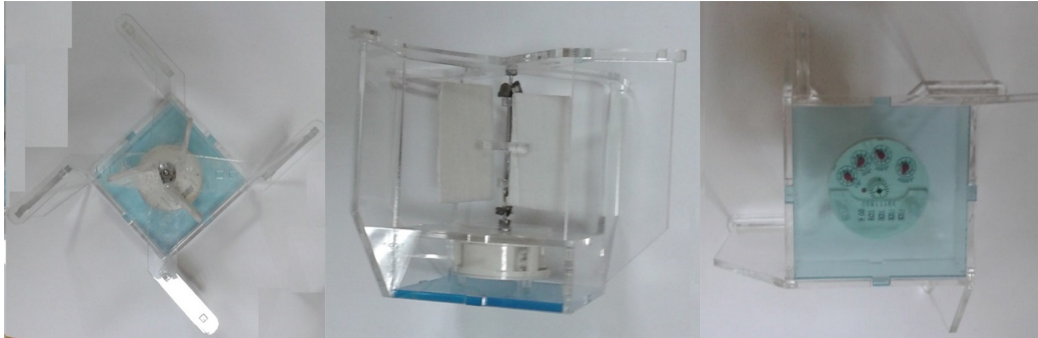


Fig. 1. The anemometer. Photo from different sides.

All parts are cut with a laser cutter. This is a durable cheap and simplified technical solution (made in Latvia).

In the end of measurement, you will receive only one figure – the total distance. Dividing it on time, you will get the average speed – $V_{average}$.

2.2. Brazometer – is a simple device for measurement of maximal possible dangerous wind gusts.

The brazmometer records only one figure – the strongest wind which occurs during long observation periods (let say during 10 years) – V_{max} .

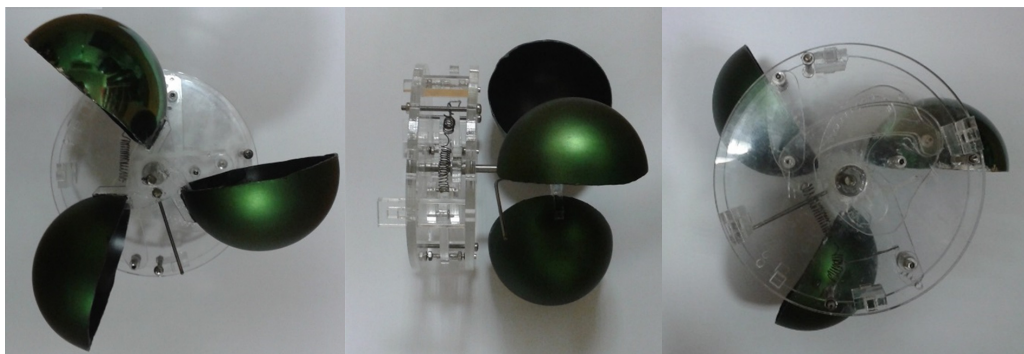


Fig. 2. The brazmometer. Photos from different sides.

2.3. Usage of logarithmic scale, or other non linear scale

Problem: The force of wind pressure is proportional to the square of wind speed. Taking in consideration that according Hooke's law the distance scales linearly with respect to that force, the value of a division on the scale should change tenfold. This is extremely inconvenient.

So the simple spring will not be suitable. That is why something like mechanisms which scales not linear but according Beaufort scale is needed.

2.4. The Beaufort scale

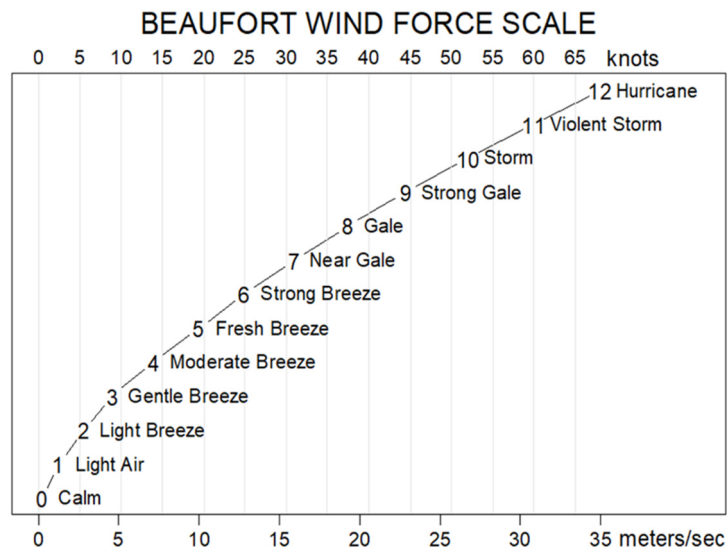


Fig. 3. This graphic is taken from Wikipedia.

There was no official algebraic definition for the Beaufort wind scale, but it looks like following:

$$\text{Wind speed (m/s)} = 0.849 * \text{Beaufort}^{1.5}, \text{ or } \text{Beaufort} = 1,12 * V^{\left(\frac{2}{3}\right)} \sim F^{\left(\frac{1}{3}\right)}$$

where V – is the wind speed in m/s. This is only my estimation – the formulae which is not mentioned in the literature. But anyway it fits to our needs.

Possible decision is to make a mechanism where the angle of the hands on the dial is proportional to cubic root of the force F (wind pressure). Such special mechanism was invented. This technical solution is in the process of being patented.

3. DEPENDENCE BETWEEN AVERAGE SPEED AND AVERAGE POWER

The power produced by the wind generator is proportional to the cube of the wind speed. Therefore, the average wind speed is not exactly the parameter that is responsible for the power produced. However, it is known from practice [12] that the speed distribution obeys approximately the Weibull distribution, which is the same in all countries and continents.

$$f(V) = \frac{K}{A} \left(\frac{K}{A} \right)^{K-1} = \left(- \left(\frac{V}{A} \right)^K \right).$$

This probability distribution in this formula is already normalized:

$$\int_0^{\infty} f(V) dV = 1.$$

Here A – is the Weibull scale parameter in m/s: a measure for the characteristic wind speed of the distribution. K – is the Weibull form parameter. It specifies the shape of a Weibull distribution.

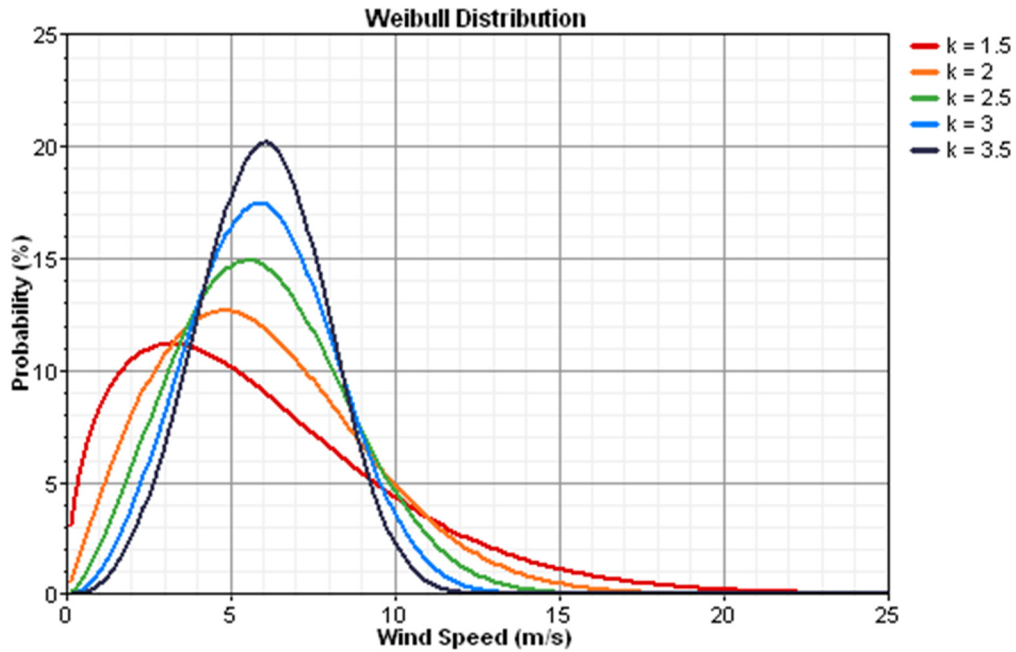


Fig. 4. Wind speed distribution for different K . Taken from [12].

Here coefficient A is proportional to the mean wind speed V_{average} . The coefficient of proportionality slightly depends on K but approximately $A = 1.13 * V_{\text{average}}$.

The total anemometer reading will be proportional to the value:

$$\text{Average}(V) = \int_0^{\infty} V * f(V) dV$$

At the same time, the total energy production will be proportional to the value:

$$\text{Average}(V^3) = \int_0^{\infty} V^3 * f(V) dV$$

Having worked a little bit with math, it is possible to get:

$$\text{Average}(V) = 0.716 * \left(\text{Average}(V^3) \right)^{\frac{1}{3}} \text{ at } K = 1.5$$

$$\text{Average}(V) = 0.806 * \left(\text{Average}(V^3) \right)^{\frac{1}{3}} \text{ at } K = 2.0$$

$$\text{Average}(V) = 0.859 * \left(\text{Average}(V^3) \right)^{\frac{1}{3}} \text{ at } K = 2.5$$

According to the study [12], in majority of locations, $1.8 < K < 2.2$ and never goes beyond the interval $1.5 < K < 2.5$. According to observations in Riga region made by Latvian Meteorological Center, $K = 2$ very precisely.

This makes it possible to compare the average wind speed and cubic root from the cubic average wind speed.

Roughly, $\text{Average}(V) = 0.8 * \left(\text{Average}(V^3) \right)^{\frac{1}{3}}$ 5% possible mistake which comes from variation of K .

This means that instead of the hard-measurable average cubic wind speed responsible for mean power, it is possible to use the mean wind speed easy measurable by a simple anemometer. And then, multiply it by a coefficient $1/0.8 = 1.25$ and raise it to the third power.

However, it should be understood that such a simple pattern does not apply to dangerous gusts of wind. The fact is that dangerous gusts of wind occur only during hurricanes. And hurricanes come from far away. They are formed thousands kilometers away above the oceans, and the local topography does not affect them as strong as the local topography affects the mean wind. Even if some dependence between two kinds of averaging still exists, it makes no sense to analyze it because during hurricanes the wind turbines do not function.

Therefore, hurricane statistics should be kept separately and not squeezed into the tail of the general Weibull distribution. For this reason, two devices are needed, but one is not enough.

4. UNEVEN DISTRIBUTION CAUSED BY DYNAMIC ATTRACTORS

Most people intuitively believe that the average wind is exactly the same at two similar points that are less than 1 kilometer apart. However, there is reason to hypothesize that this is not always the case, and the difference can be sufficiently large. This hypothesis is based on three arguments:

4.1. Small-scale argument

It is known that hydrodynamic movements tend to repeat itself. May be the movements are repeated in different ways in different places but always the same way in the same place. The smallest relief differences can lead to repetitions of very different movements in close and almost identical places. To illustrate this, you can make a simple experiment: watch how water boils in a pan. You will easily notice that bubbles start always from the same points and do not start from others points at all. And this happens despite the fact that in a round pan all the symmetrical points are practically equal, and therefore, intuitively, one would expect that the bubbles will start with equal probability from all symmetrical points. However, the smallest differences in roughness at the bottom destroy this symmetry. For example, observations of such unevenness in Melbourne can be found here [6]. Hydrodynamic motions multiply any small violation of symmetry and stably repeat the same dance. In the language of mathematics, such repetitions are called: dynamic attractors. There is a reason to put forward a hypothesis that dynamic attractors take place also for the wind movements.

4.2. Large-scale argument

Nowadays, only large-scale statistics is available in internet, for example, in Ref. [19] you can find statistics for many years 1980–1999 in USA. Gif files for different 5-year periods show that tornado and thunderstorm come again and again in the same place. In language of mathematics, they can be called tornado-attractors. But if this repeating in large scale, we can hope to find similar repetition in small scale, because according to Mandelbrot Fractal theory, what happens in large (national wide) scale takes place also in small scale (about 1 km).

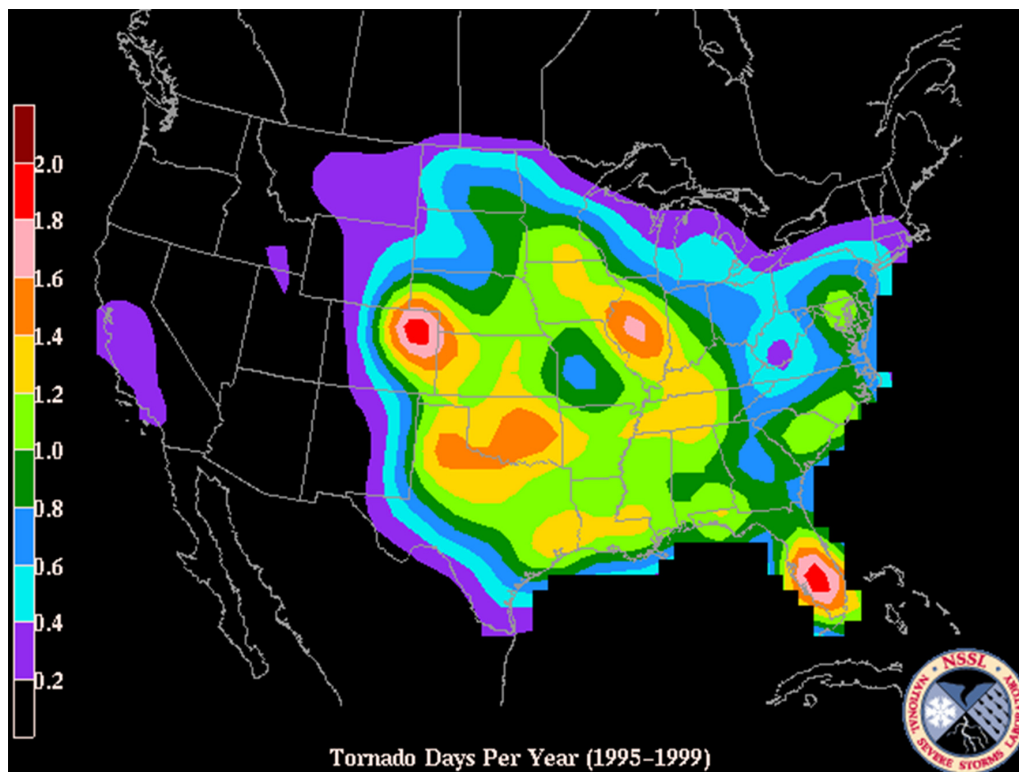


Fig. 5. Taken from Ref. [19].

<https://www.nssl.noaa.gov/projects/hazard/img/ttor9599.gif>

4.3. Argument based on formation of geographic relief

It is known that the whirlwinds of tornado roam the same routes from year to year: for centuries, they destroy the forest in the same places, which leads to the formation of natural forest glades. During thousands of years, the wind blows sand to the same places, resulting in the formation of hills. It is not yet clear: in what natural conditions such an uneven distribution of gusts and average winds takes place. Seif dune (barkhan) is the easiest visible result of such wind's unevenness. Please see Figure 6.



Fig. 6. Seif dune (barkhans) is a consequence of uneven wind on a scale of hundreds of meters. Image from Ref. [10].

So far, no one has made direct precise measurements to confirm or refute this hypothesis in scale of 1 km. To confirm it, hundreds of wind measurements and their averaging over a long period over a small practically uniform area are required. If this hypothesis will be confirmed, then the instruments will show different average wind and different maximal wind for a long observation period in places that are less than 1 km apart from each other. This difference may occur the same from year to year, which means that it must be taken into account when choosing the location of wind turbines.

I hope that the cheap mechanical devices described above in this article can be useful to those who plan to build wind generators and want to find the best place.

5. PHYSICS OF WIND FROM ECONOMICAL ASPECT

The idea of mean wind speed which is devaluated by hurricanes (name proposed: “Bojat wind speed”).

A wind generator has its own cost, which is an investment. The cost price is proportional to the weight of materials spent on construction. And the weight of the materials used is proportional to the required strength. The dangerous breaking pressure that some gust of wind can exert is proportional to the square of the wind speed V .

Therefore, it can be argued that the cost of building a generator is proportional to the square of the maximum possible speed of a gust of wind in a given location. Some estimation of real average price can be found here [13], [18], [4] and [14], but it is clear that there are different models in the market: some of them can hold very strong hurricane the other not, and it is reason why they cost differently.

In this economic game, underestimation leads to the loss of all money as a result of the destruction of the wind turbine, and overestimation leads to unnecessary construction costs.

If the maximal possible speed is estimated correctly, then the investment can be considered proportional to the square of the maximal wind speed.

On the other hand, it can be considered that the income received is proportional to the power of the wind generator, which is proportional to the average cube of wind speed or cube of average speed.

Therefore, the income from investments in wind energy will be proportional to one parameter:

$$V_{\text{Bojat}} = \frac{V_{\text{average}}^3}{V_{\text{max}}^2}$$

where V_{average} is the average wind throughout the year and V_{max} is the maximum possible dangerous gust of wind during a storm. V_{Bojat} is one integrated parameter which helps us to evaluate suitability of the place for wind power.

Accordingly, the payback period for investment in wind energy will be inversely proportional to this parameter.

This parameter has big advantage because it is purely physical. It is nothing else but some effective speed measured in meters per second by a purely physical method using the two instruments described above in this article. The name is suggested: average wind speed devalued by hurricanes. Let us name it here as the Bojat speed (from Latvian language *Bojats* – spoiled, devaluated). It will always be significantly less than the real average wind speed. In theoretical ideal case if the wind is constant, the formulae gives: $V_{\text{Bojat}} = V_{\text{average}} = V_{\text{max}} = \text{Constant}$, but in reality $V_{\text{Bojat}} < V_{\text{average}}$.

For economic calculations and for making final decision: to build or not to build, it should be multiplied by all kinds of economic coefficients such as the cost of electricity, profitability of a bank loan, demand for electricity and so on. How to take in to consideration all this non physical parameters and reduce all of them to one value can be found here [3]. But in our article we discussed only physics.

Information on average wind speed devalued by hurricanes (Bojat speed) is a basic physical parameter for wind energy and should be measured before any consideration of future construction begins.

From two places, the one with the best V_{Bojat} parameter should always be chosen.

Unfortunately, till now, only the average wind is available in internet. This leads to erroneous conclusions, for example:

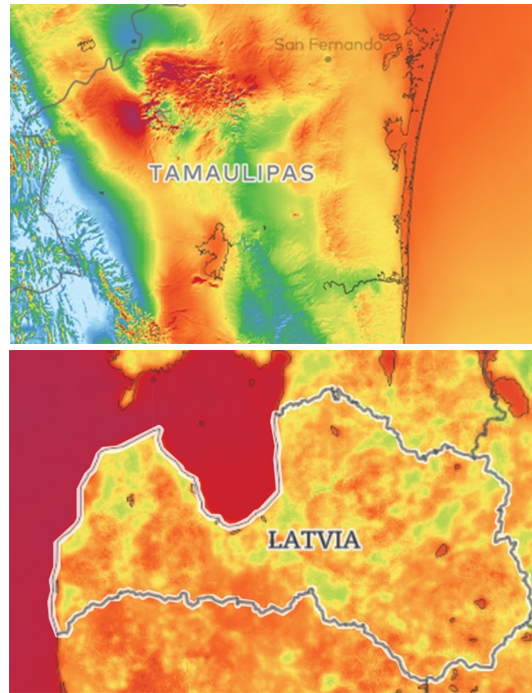


Fig. 7. Average wind power. Mexico (up), Latvia (down).
Pictures are taken from Ref. [15].

Looking at these maps, you might think that Latvia and Mexico have roughly the same opportunities for wind energy development because both have areas marked by brown color which symbolize average wind speed $V_{\text{average}} = 8 \text{ m/s}$. But it is incorrect conclusion. Hurricane Patricia south of Mexico, in 2015 achieved its record peak intensity with maximum wind gust of $V_{\text{max}} = 96 \text{ m/s}$ [17]. On the other hand, for Latvia, the maximum wind gust was in 1967, $V_{\text{max}} = 48 \text{ m/s}$ [16].

Using above formulae, we calculate: $V_{\text{Bojat}} = 0.055 \text{ m/s}$ for Mexico and $V_{\text{Bojat}} = 0.22 \text{ m/s}$ for Latvia.

So, Latvia has the areas which are four times more profitable for wind energy than Mexico! Not because the mean wind is stronger but just because there is no need to make the Latvian wind turbines as hurricane-proof as in Mexico; so, they can be made four times cheaper.

The essence of proposed method is that two parameters are reduced to just one integrated parameter. This idea is not unique: for example, Baseer et al. [3] introduce some “site suitability index” which integrates many physical and economical parameters. This index represents final easy to read evaluation for decisions makers. It is interesting to look on their map for Saudi Arabia:

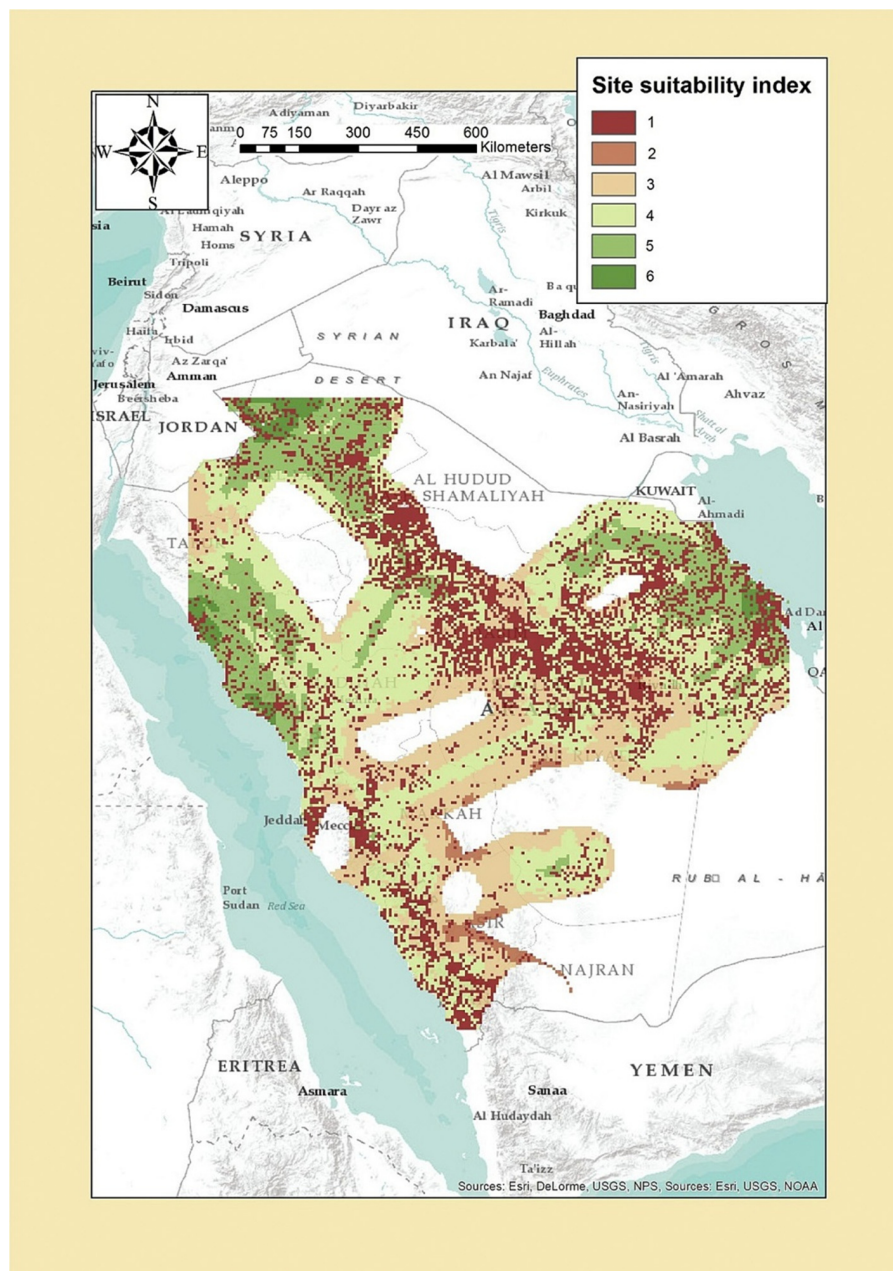


Fig. 8. Taken from the study by Baseer et al.[3].

Note that this map looks very similar to a fractal (as also the map of Latvian average speed of wind on Figure 7 does). It can be assumed that if going to smaller scales <1 km, such fractal scatter will continue to look very chaotic.

The advice to measure the average wind speed during at least a year not only in the region but in exact place can be found in many publications, for example here [11]. In addition to this advice the necessity to measure not only average speed, but maximal speed in hurricane should be emphasized. So two devices will be needed.

6. HEIGHT

At [8] and [9] big discussion about wind dependence from height can be found. But as soon as our goal is to simplify things – for all measurements one standard height should be chosen. The height 10 meters is traditionally recommended for measurements by anemometer and brazmometer. It is clear, that real planned wind turbine will work at higher height, and some corrections will be needed. The good discussion about optimal size of wind turbine is here [1].

7. CONCLUSIONS

The average wind speed devalued by hurricanes V_{Bojat} is much more informative than just average wind speed. It would be nice in future to see map colored by V_{Bojat} .

Sets of two described devices are suitable to measure the V_{Bojat} . Hundreds or such devises should be produced and used for further study of wind in any country.

7.1. Non-yet solved scientific question:

Could the average wind be sufficiently different at similar points less than 1 km apart from each other?

Thousands of devices and many years of observation are required to answer this question. I hope that the instruments described above will be proven useful for such research. This requires funding.

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