Study to evaluate the effect of terrain surface on performance of a wind farm in Ninh Thuan province, Vietnam

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Abstract. Topography is one of the important factors directly related to the distribution of wind resources, so it plays an important role in determining the layout and operation efficiency of wind power farms. In this research, we use a combination of Computational Fluid Dynamics (CFD) method and Geographic Information Systems (GIS) data to determine suitable locations for building wind turbines in complex terrain conditions. The selected region to build the analytical model is an area with many hills and mountains adjacent to the East Sea, in Thuan Nam and Ninh Phuoc districts, Ninh Thuan province. The first part, this article will provides a general method for determining the best locations for installation of wind turbines according to specific terrain conditions. Then, apply this method to build accurate 3D models for the area, the models are meshed by hexagonal elements combined with tetrahedron elements with side lengths of 200m. The results obtained from the models are the distributions of wind speed by altitude at specific locations such as mountain peaks, mountain slopes, valleys of the area pointed out. Based on these results, the locations with high and stable wind speed, suitable for wind turbine operation are suggested. In addition, the article also presents some locations where wind with high turbulence or eddy winds may appear, which may adversely affect turbine performance. Finally, the paper gives an optimal location map for a wind farm with a capacity of less than 100MW using a turbine with a 4MW capacity.
Keywords: Wind Resources, Wind Power Plant Layout, GIS Data, CFD Method, Turbine Blade Breakage.

1 Introduction

Currently, the energy crisis is causing many obstacles to socio-economic development in many countries around the world. In addition, the effects of climate change are also becoming increasingly apparent, causing enormous damage globally. To prevent the worsening of climate change, many countries have come together to agree and commit to cutting CO2 emissions. At the 26th United Nations climate change conference (COP26) taking place in

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Glasgow, representatives of countries signed a commitment to reduce and gradually eliminate factories using fossil fuels, and prioritize the development of renewable energy [1]. In Vietnam, according to the contents of the national power development plan in the 2021-2030 period, with vision to 2045 of the Institute of Energy, Ministry of Industry and Trade, the theoretical potential of onshore wind power of Vietnam is about 179.8 GW and the theoretical offshore wind power is 475 GW [2]. However, Vietnam's terrain is very diverse and complex, with many mountainous areas alternating with valleys and surfaces adjacent to the sea. Therefore, there is a need for research on the influence of terrain on the potential to exploit wind resources for each specific location.

In order to build a wind power farm with the best performance, it is necessary to conduct a survey on the distribution of wind sources according to the topography in the selected area. Current research on wind sources mainly relies on satellite data to build wind maps for large areas, with spatial resolution ranging from 1 km to several tens of kilometers [3, 4]. Therefore, the influencing factors of terrain within a narrow range are almost not considered. This is the main cause leading to many incidents and accidents that damage the blades of wind turbines, causing huge economic losses. In the publication of H. G. Kim et al. [5], this group also conducted analytical models on the terrain characteristics of Korea, focusing on mountainous and island terrain areas. From there, an assessment of the potential of wind resources in Gangwon province is made. Recently, a number of research groups around the world have conducted analytical models for small areas, however these groups mainly rely on GIS satellite data [6-8]. These wind source assessment publications are mainly based on past meteorological data, re-analysis data, combined with statistical methods to conduct simulations and make forecasts. In this study, Blender GIS data will provide highly accurate topographic features, combined with mathematical models of fluid dynamics in Ansys CFX software. The motion of the wind flow will be calculated in a 200m spatial resolution.

To determine the distribution of wind speed by altitude, we use the following formula [9]:

$$\frac{v_h}{v_{h_0}} = \left(\frac{h}{h_0} \right)^{\alpha} \tag{1}$$

Where: h, h_0 are the altitude at any position h and the predefined position h_0, respectively, m; v_h and v_{h0} are the velocities at h and h_0 respectively, m/s; α is a coefficient that depends on the type of terrain.

In the case of terrain with obstacles and unevenness, the wind flow will be turbulent and the distribution of wind speed may be changed greatly as shown in Figure 1.

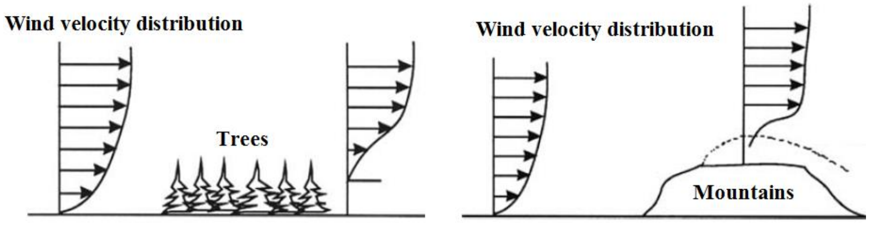

Fig. 1. Wind speed distribution changes when encountering forests and hills [9].

In fact, the mainland of Vietnam is mainly mountainous and the terrain has a large difference in height, so we need to have research for each specific plant construction location to be able to determine the most accurate wind velocity distribution. In this study, we selected the mountainous area of Ninh Phuoc district, adjacent to Ninh Thuan and Binh Thuan provinces, this is a place with high wind speed, suitable for building a wind power farm. To model the accurate terrain of this area, the research team used Blender GIS data and then converted it into Ansys CFX software format to make settings and run analysis based on the

CFD method. As a result, wind speed distributions with altitude at points such as valleys, mountain slopes, and mountain peaks will be shown. Then, the best points for the installation of 4MW wind turbines from Vestas are also proposed.

2 Methodology

2.1 Blender GIS

Blender is an open source software that helps users create realistic three-dimensional models, which can run on platforms such as Linux, macOS, and Windows [10]. Blender GIS data will be loaded into the Blender software library to create 3D spatial terrain maps from Google satellite image data [11]. Any analyzed areas can be defined by entering latitude and longitude coordinates or selected by hovering over the Blender software.The working interface of Blender software is shown in Figure 2.

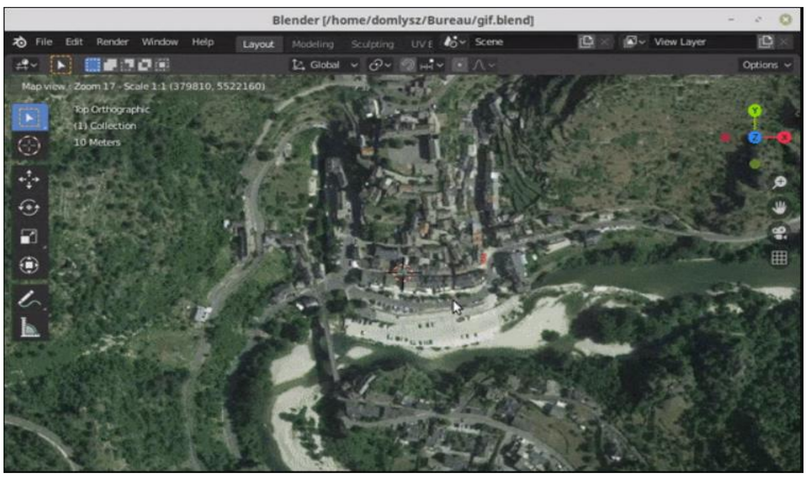

Fig. 2. Creating 3D models on Blender software [11].

2.2 CFD method

The CFD method is a research method dedicated to the formation and movement of fluids, including also transmission processes, heat transfer and chemical reactions. The physical characteristics of fluid motion are described through mathematical equations in partial differential forms. This system of mathematical equations is known as the control equation system. To solve the system of equations, we need to use high-configuration computers. The main contributing processes to the CFD method are shown as in Figure 3 [12].

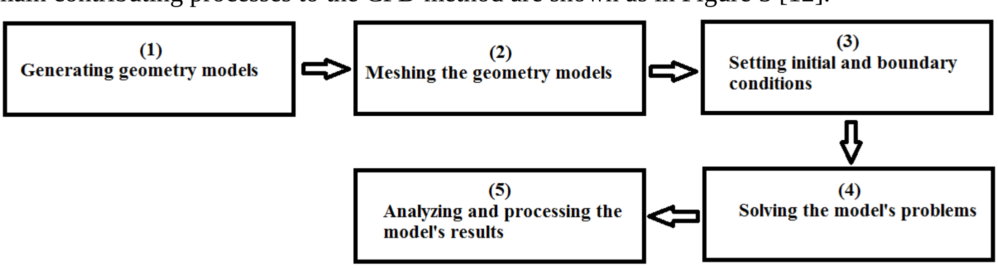

Fig. 3. The analysis steps in Ansys CFX.

Ansys CFX is software owned by Ansys corporation, this software is very commonly used in advanced countries around the world in the field of designing pump impellers, and blades of different types of turbine, including wind turbine. The solver of this software is based on the CFD method and has a number of modern support tools to help users solve problems related to fluids with high accuracy [13].

2.3 Building the analytical models

Firstly, the terrain of the mountainous area in Ninh Phuoc commune was modeled using Blender GIS data and then transferred to Ansys CFX software for complete editing. The model has a rectangular shape with a width of 12000m, a length of 16000m and an altitude of 900m above sea level as shown in Figure 4.

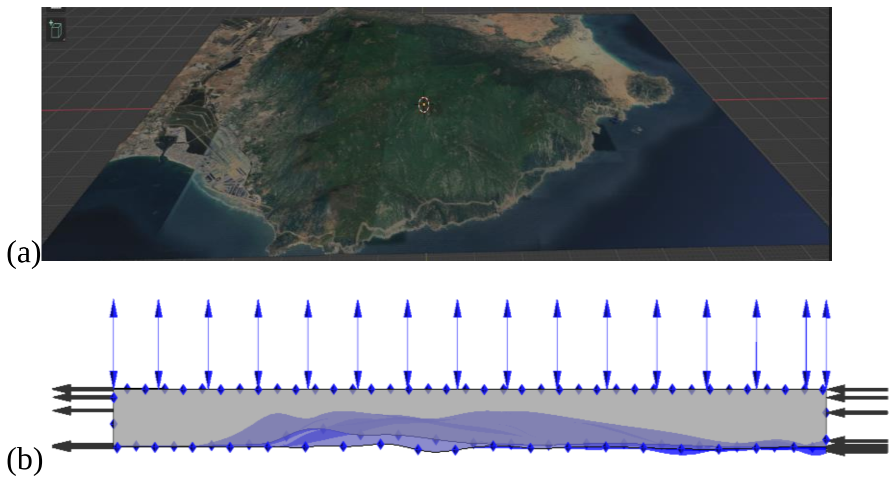

Fig. 4. The specific region on Blender (a) and its model on Ansys CFX (b).

The model is then meshed into smaller spaces, the mesh size is 200m, this means the spatial resolution of this model is 200m. The type of mesh used is a combination of Quadrilateral and Hexagonal grids, the total number of meshes of this model is about 385000 meshes. The meshing quality of the entire model is approximately 0.85, which is good meshing quality.

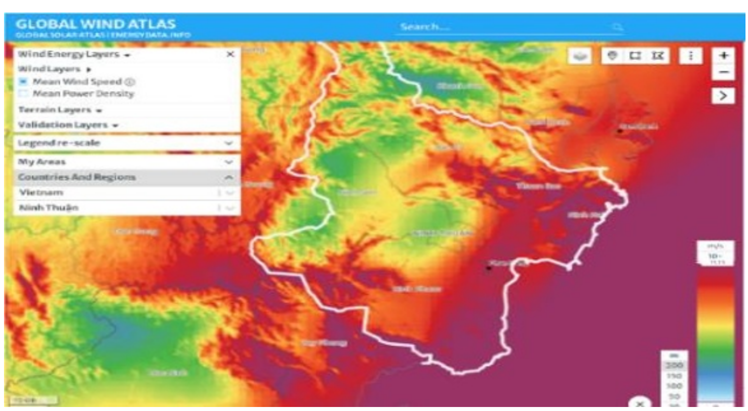

Fig. 5. Satellite data on wind resources according to the World Bank [14].

The model is set up with boundary conditions for the wind blowing from the East Sea to the East-West direction, the two sides and top planes of the model are set up in open interaction conditions as shown in Figure 4b. To determine the initial conditions of the wind velocity distribution for the model, the authors used data provided by the World Bank at the altitudes of 10m, 50m, 100m, 150m and 200m. These data are shown in Figure 5 and Table 1 [14].

Table 1. Distribution of average wind speed according to height in the sea area adjacent to the mainland area.

No.	h, m	$\bar{v}$, m/s
1	10	8.2
2	50	9.5
3	100	10.4
4	150	10.9
5	200	11.3

From Formula (1), the authors conducted a function fitting to find the distribution function of wind speed according to altitude in the sea area adjacent to the mainland, the graph of the fitting function is presented in Figure 6.

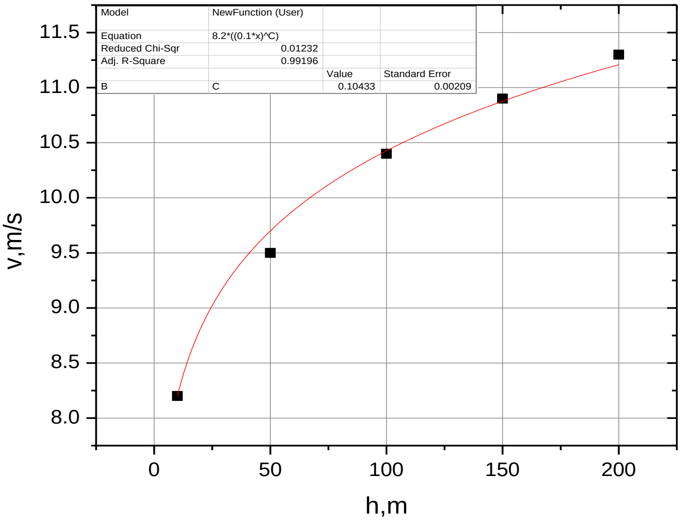

Fig. 6. Fitting the function of wind speed distribution according to altitude.

The distribution function of wind speed by height at the entrance surface of the model is determined from Figure 6 as follows:

$$v_h = 8.2 \times \left(\frac{h}{10} \right)^{\alpha} \tag{2}$$

with: $\alpha = 0.10433 \pm 0.00209$.

Formula (2) will be used to set the initial velocity value at the entrance surface of the model at altitudes from 0m to 900m. Other initial conditions at the entrance plane of the model such as temperature and pressure are T_{in}=25^{o}C and P_{in}=1atm, respectively.

3 Results and Discussion

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The analytical model is built and the boundary condition parameters are set based on the combination of Blender and Ansys CFX softwares as shown in Figure 4. The input surface of the model is assigned a velocity distribution function according to altitude as in Formula (2). The whole model will be analyzed in steady state with a total of 2000 iterations, the convergence criterion is 10^{-10}. Because the wind motion in this case is turbulent, the turbulence model chosen is the shear stress transport model.

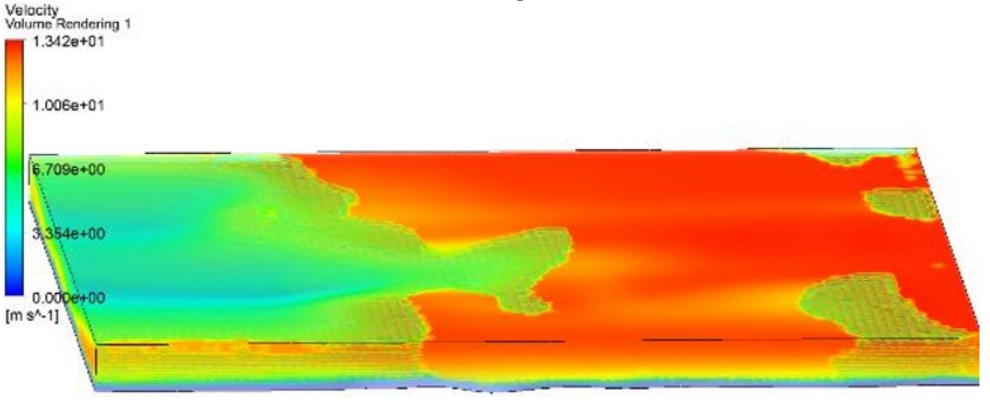

Fig. 7. Distribution of wind speed in the 3D whole model.

After the solution processes ended, in order to have an overall assessment of the wind speed distribution in the entire model, the authors processed and produced the wind speed distribution in 3D space as shown in Figure 7. From Figure 7, we can see that the front ridge areas, blowing in from the East Sea direction, will have higher wind speed values than other areas. In contrast, the rear ridge areas, the western slope, have very low wind speeds. The reason for this difference can be roughly explained as when the wind meets the front ridge, the space will be narrowed, leading to the velocity having to increase to ensure the law of mass conservation. In case the wind goes to the behind mountainside, the wind will create vortices along the terrain, from which the wind directions will cancel each other, leading to a significant decrease in the value of the wind speed.

Figure 8 shows details of wind speed distribution according to height from sea level. Wind speed distribution has a large change as height increases. For a more detailed survey, in this study, we assume a 4MW wind power turbine from Vestas corporation will be installed in this area. Some main parameters of this turbine are given in Table 2.

Table 2. Some main parameters of 4MW Vestas wind turbine [15, 16].

Parameters	Value	Parameters	Value
Model	V150/4000	Cut-in wind speed, m/s	3
Rated power, MW	4	Rated wind speed, m/s	9.9
Rotor diameter, m	150	Cut-off wind speed, m/s	22.5
Swept area, m^2	17672	Tower: minimum hub height, m	105
Specific area, m^2/kW	4.42	Tower: maximum hub height, m	166
Number of blades	3	Generator: Maximum speed, rounds/minute	1485

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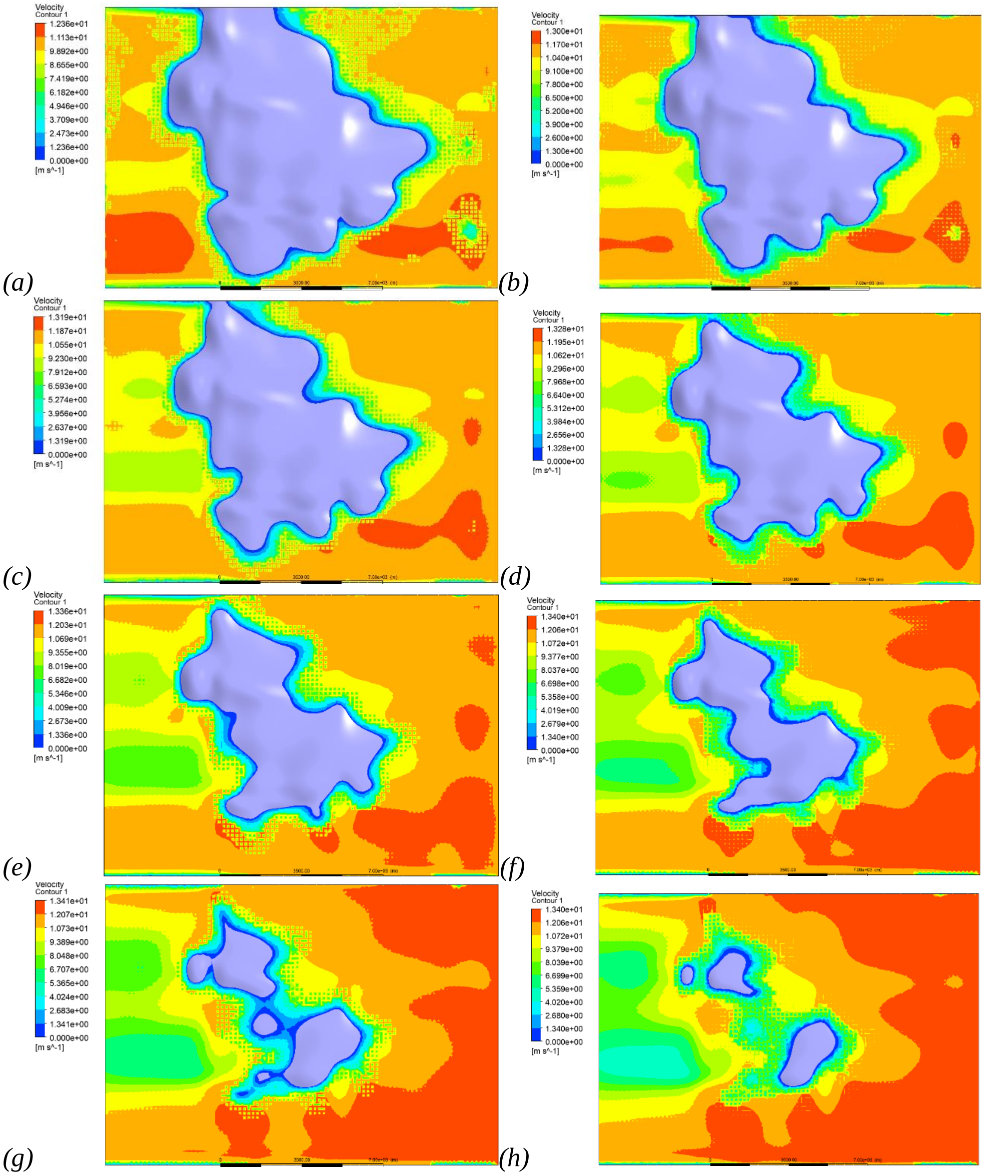

Fig. 8. Wind speed distribution at the height (a) z=166m, (b) z=216m, (c) z=266m, (d) z=316m, (e) z=366m, (f) z=416m, (g) z=466m and (h) z=516m.

When considering the actual height of the turbines as shown in Table 2, the maximum tower height is 166m, combined with the blade length of 150m, the total height of the tower is about 316m. The installation position of each tower can be about 1000m apart to ensure the stability of the wind source. From the data in Table 2, we see that the operating wind speed of this type of turbine is from 3m/s to 22.5m/s, however the nominal wind speed is 9.9m/s. Therefore, locations where wind speeds reach 9.9m/s or more will be the most suitable places to install these turbines. Figure 9 shows details of areas with wind speeds greater than 9.9m/s.

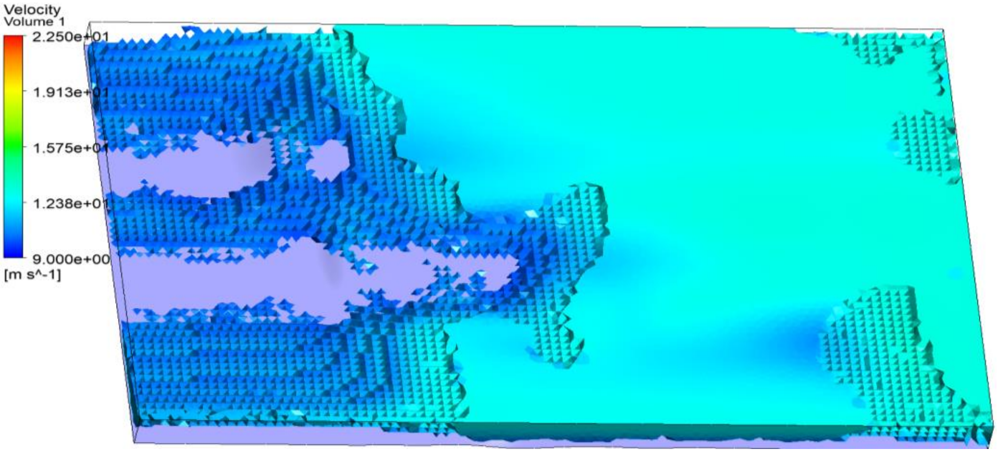

Fig. 9. The areas with wind speeds greater than 9.9m/s.

As the data shown in Figure 8 and Figure 9, we see that the areas from the eastside to the center of the model, the mountain top, have wind speeds greater than 9.9m/s and are suitable for installing the wind turbines. The length of the suitable region is 12000m and the width is about 6000m. Assuming these turbines are installed in horizontal rows, each tower is 1000m apart, then each row according to the width of the model will be able to install 12 towers, according to the length of the model. The model can be installed in up to 5 rows. The total number of wind turbines that can be installed will reach 60, corresponding to a total capacity of 240MW.

However, Vietnam often experiences major storms, which can affect the integrity of turbines. Therefore, considering the case of very strong storm winds with level 12 in according to the Beaufort wind scale [17], the wind speed reaches from 32.19 m/s to 37.10 m/s. The selected velocity is 35 m/s and the turbulence intensity is 10%.

From Figure 10, when a big storm occurs, the areas from the middle of the model to the southern edge of the model is where the wind is very strong, the wind speed can be up to more than 40m/s. This can cause problems such as broken turbine blades, causing serious economic and safety losses of the plant. The difference in wind velocity distribution on the two sides of this model is mainly due to their different topography. The southern area has many hills and mountains, when the wind blowing from the sea will collide with obstacles that are hills and mountains, it will cause a change of direction, the wind will flow more strongly, leading to an abnormal increase in wind speed. This change in velocity will become more apparent as the incoming wind speed increases. In contrast, the northeast region of the model is flat land, so the wind velocity over this area will always be more stable than all the rest. Figure 11 clearly shows the direction of the wind source in both these areas.

Because of the safety of turbines throughout their operating life, the areas where the turbines can be installed will be the northeast of the model, and the number of installed turbine towers is about 25, which equates to a total capacity of 100MW.

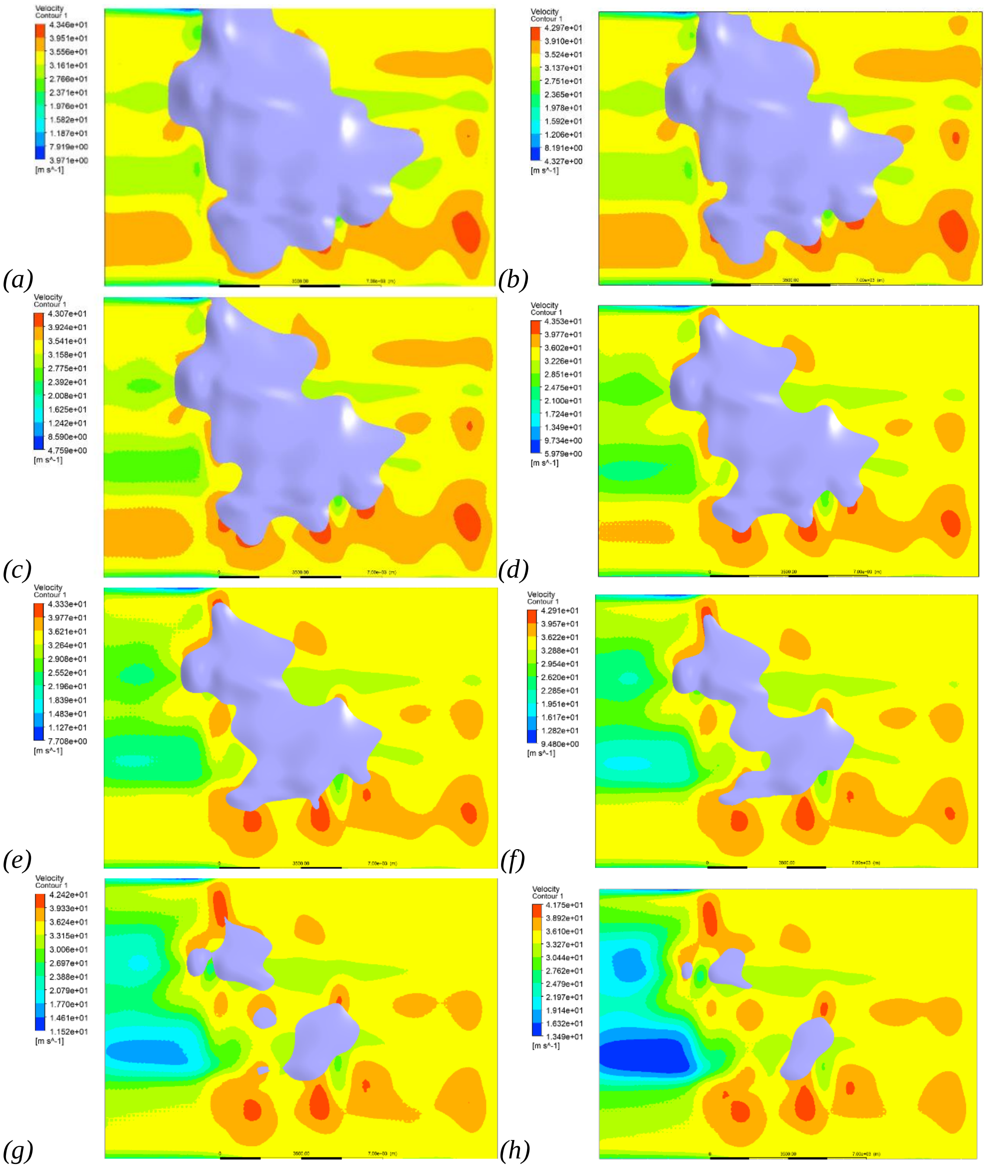

Fig. 10. Wind speed distribution during storms at the altitude (a) z=166m, (b) z=216m, (c) z=266m, (d) z=316m, (e) z=366m, (f) z=416m, (g) z=466m and (h) z=516m.

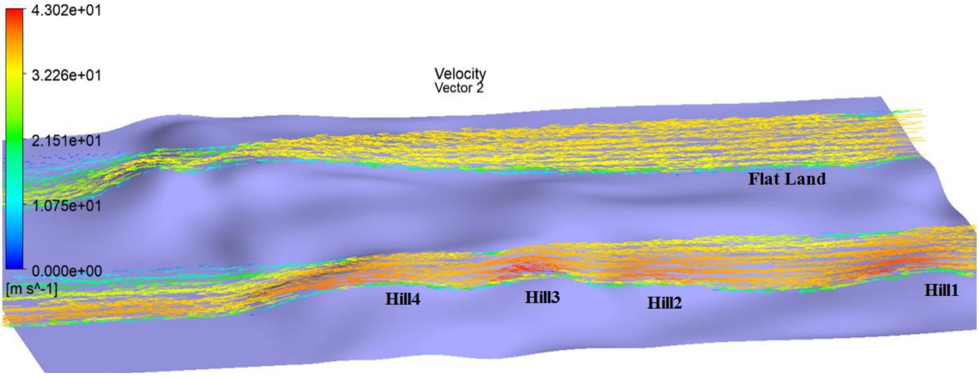

Fig. 11. Flow vectors over two diffirent regions.

4 Conclusion

From the results presented in this paper, we can conclude that it is necessary to research and evaluate wind resources at locations where specific wind power plants are expected to be built. From there, we can choose the most suitable type of wind turbine and installed locations, avoid wasting investment and improve efficiency. In the case of this analysis, the area is large and has very good wind kinetic energy, but when examined closely, only about one-fifth of the area is suitable for installing wind turbine towers.

Ansys CFX software combined with Blender GIS satellite information can solve the problem of assessing wind energy in a specific area, the results obtained can be in the form of qualitative images or quantitative graphs. All obtained results are very clear and highly reliable.

References

1. United Nations. Delivering The Glasgow Climate Pact. Available at: https://ukcop26.org/ (accessed April 25, 2023).
2. Institute of Energy, Ministry of Industry and Trade of The Socialist Republic of Vietnam. The National Power Development Plan in the 2021-2030 period, with vision to 2045 (in Vietnamese). May 2023.
3. Dinh Q. V., Doan Q. V., Ngo D. T., Dinh V. N., Nguyen D. D. Offshore wind resource in the context of global climate change over a tropical area. Applied Energy, 2022, Vol 308, Art. No. 118369.
4. Nguyen V. H., Pham X. T., Nguyen D. N., Nguyen X. A., Pham L. K., Hoang H. S., Nguyen T. M., Pham C. C. Observation and Simulation of Wind Speed and Wind Power Density over Bac Lieu Region. Advances in Meteorology, 2021, Vol. 2021, Art. No. 8823940.
5. Kim H. G., Kang Y. H., Kim J. Y. Evaluation of wind resoure potential in moutainous region considering morphometric terrain chereacteristics. Wind Energy, 2017, Vol. 41, No. 2.
6. Effat H. A., El-Zeiny A. M. Geospatial modeling for selection of optimum sites for hybrid solar-wind energy in Assiut Governorate, Egypt. The Egyptian Journal of Remote Sensing and Space Sciences, 2022, Vol. 25, No. 2.

7. Back Y., Kumar P., Bach P. M., Rauch W., Kleidorfer M. Integrating CFD-GIS modelling to refine urban heat and thermal comfort assessment. Science of the Total Environment, 2023, Vol. 858, Art. No. 159729.
8. Chang S., Jiang Q., and Zhao Y. Integrating CFD and GIS into the Development of Urban Ventilation Corridors: A Case Study in Changchun City, China. Sustainability, 2018, Vol. 10, No. 6.
9. Manwell J., McGowan J., Rogers A. Wind energy explained : theory, design, and application. John Wiley & Sons Ltd., 2009.
10. Blender. Blender 3.4 Reference Manual. Available at: https://docs.blender.org/manual/en/ latest/getting_started/ about/introduction.html (accessed April 25, 2023).
11. GitHub, Inc. BlenderGIS. Available at: https://github.com/domlysz/BlenderGIS (accessed April 25, 2023).
12. Tu J., Yeoh G. H., Liu C. Computational Fluid Dynamics: A Practical Approach. Elsevier Inc., 2008.
13. Ansys Inc. Ansys CFX. Available at: https://www.ansys.com/products/fluids/ansys-cfx (accessed April 25, 2023).
14. World Bank Group. Global Wind Atlas. Available at: https://globalwindatlas.info/en/area/Vietnam/Ninh%20Thu%E1%BA%ADn (accessed April 25, 2023).
15. Vestas. 4MW-platform. Available at: https://www.vestas.com/en/products/4-mw-platform (accessed April 25, 2023).
16. Wind Power. Vestas v150-4000. Available at: https://www.thewindpower.net/turbine_en_1490_vestas_v150-4000-4200.php (accessed April 25, 2023).
17. National Weather Service – USA. Beaufort Wind Scale. Available at: https://www.weather.gov/mfl/beaufort (accessed April 25, 2023).