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On the possible wind energy contribution for feeding a high altitude Smart Mini Grid

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Abstract

The use of renewable energy sources to increase electricity access, especially in *remote areas* as high mountains, is a possible contribution to poverty reduction, climate change mitigation and improved resilience. In this paper an evaluation of the wind potential of a remote area in Nepal is performed, using CFD methods and the simulation of a micro wind turbine projected by Perugia University. With an accurate analysis of wind data and air density effects it is possible to test energy production potential in areas with high average wind speed. The overall estimated production for each turbine is an interesting result and an easily exportable contribution to the perspective of sustainable development at very high altitudes and remote areas.

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Keywords: high altitude; rural electrification; wind energy; wind meso and micro modeling.

1. Introduction

In the last 20 years, the exploitation of non-renewable resources and the effects of their applications on environment and human health were considered central topics in political and scientific debate at worldwide scale. Both on legislative and research level, attention is focused on the adoption of systems

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that aim at energy saving and use of renewable energies, in a "*rational use of energy*" scenario. Numerous technical solutions have been developed in order to save energy, avoid GHG emissions and then face the climate change. *Distributed Generation* (DG), i.e. any source of electric power of limited capacity, directly connected to the power system distribution network where it is consumed by the end users, has gained a lot of attractions in the power sector due to its ability in power loss reduction, increased reliability, low investment cost, and most significantly, to exploit renewable energy resources. The annual distributed renewable generation capacity around the world is estimated to increase from 6,000 in 2009 to 17,000 MW in 2015 [1-2]. Using renewable energy sources to increase electricity access, especially in *remote areas* as high mountains, would contribute to poverty reduction, climate change mitigation and improved resilience. An off-grid power generation system that is reliant on different renewable and conventional energy sources and distributes power through a local grid network is often known as a *smart mini grid* [3-4]. This technology occupies a middle ground of electrification options between traditional network extension and individual home systems, with a range of potential benefits and risks [5]. A *characterization process* should be undertaken to avoid assessment mistakes in terms of real sustainability. *Upstream processes* include raw material extraction, transformation and transports, often carried out in extreme conditions (e.g. along trekking routes). During the *electricity generation phase*, energy balance is affected by the specific atmospheric conditions, as air density or solar radiation. Finally, *downstream processes* may consider different waste treatments (reuse, recycling and/or landfilling). Therefore potential energy savings and avoided GHG emissions from renewables should be evaluated from a whole life cycle perspective [6].

This study is focused on the possible exploitation of wind energy potential in a high altitude large area. The wind potential is strongly affected by variability in time and space, but an accurate study of the anemology of the area can help to figure out possible uses. Wind energy may give an important contribution to the energy balance in off-grid areas, where even other energy sources are variable and not programmable [3, 7].

2. Study area

The study is geographically focused within the Khumbu Valley, located in the central part of the Himalayan Range; this area is strategic to study climate change and its effects on mountain ecosystems, containing the southern half of Mount Everest and its summit (8,848 m).

The Khumbu Valley partially includes the Sagarmatha National Park (SNP), a wide area on the Nepalese mountainside of Everest and declared as World Heritage Site since 1979. In recent years the park was the focus of several studies and initiatives, aimed at improving the management of its many-sided ecosystem, significantly influenced by climate change and by the increase of human activities (e.g. tourism). The scarcity of energy resources in some sub-realities of the park constrains local people to burn strongly impacting fuels that, together with bad daily habits and obsolete technologies, cause high levels of indoor air pollution. This reduces the quality of life and determines a number of respiratory diseases especially in elderly people, women and children.

Because of the lack of a regulation on forests conservation management, an over-consumption of firewood contributed to a progressive deforestation and consequent alteration of the hydro-geological system [8-9].

2.1. Available resources and energy balance

Renewable energy sources are freely available in the region, but energy produced from these sources is still rather scarce (overall little more than 10%). In particular, the park already hosts n. 6 *hydro*power stations with a capacity ranging from 15 kW to 630 kW, plus others pico size-hydropower (< 5 kW). On average Nepal has 6.8 sunshine hours per day with the intensity of solar irradiation ranging from 3.9 to 5.1 kWh/(m^2*day), with a commercial potential of solar power for grid connection estimated in 2,100 MW. *Solar PV* systems are used widely for lighting in Khumbu [10]. *Solar thermal* panels, used to heat water, were found mainly below Pheriche. Very small-scale (capacity between 0.1 and 0.5 kW) *wind* power systems are in operation in the Upper Khumbu, while isolated large-scale ones have not been built so far, mainly due to thin air density, higher costs of installation at these altitudes, and negative visual impact on the landscape for tourism industry. Recently, Nepal has started to generate energy with use of small-scale applications of wind power, in single homes or rural villages, and encouraging results have been achieved [11].

As for electricity network, Namche, Khumjung and Chaurikharka are connected to a local grid, determining a positive decrease in firewood consumption. At park level, the yearly energy deficit is around 7%, with an error of ± 5% (4,000 kWh). The really critical situation is evident at the settlement level, with the majority of settlements in energy deficit condition (even over 50%) compared to the energy demand [8-9].

2.2. Namche Bazar

Namche Bazar (Fig. 1) is the main settlement and trading center of Khumbu region, with many Nepalese officials, a police check, lodges and stores. It is located in a central point both from a logistical and altitude/weather points of view. Namche is well known to trekkers in the Khumbu region, especially for altitude acclimatization, and is the gateway to the high Himalayas.

Namche Bazar was selected as possible experimentation context. Currently it is connected to a local hydropower grid, and solar thermal panels are used for hot water production. Within the collaboration with Sagarmatha Pollution Control Committee and Eco-Himal, Ev-K2-CNR Association (more details below) promotes and developes a program for waste management in this area, including the installation of a waste disposal system incinerator. To create a small waste collection center in Namche, an additional disposal device is under design: simple to be built, moved, assembled and installed; optimized and sometimes automated; easy to work.

In order to evaluate the possibility to provide small stand-alone wind power systems or hybrid systems in combination with PV systems [12-13], the wind energy potential has been assessed.

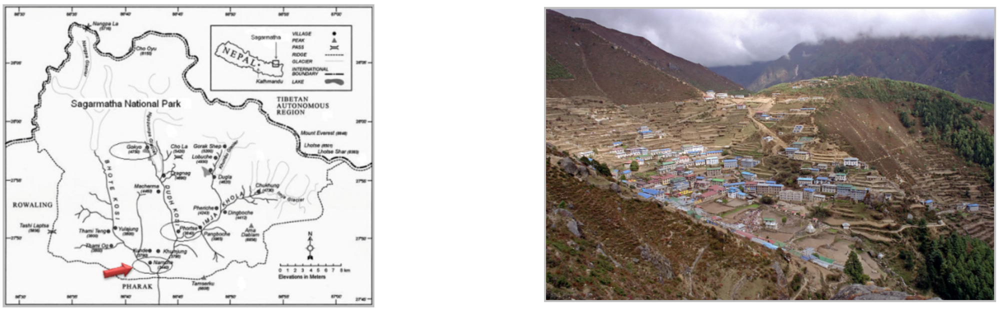

Fig. 1. Namche Bazar, Solukhumbu district, Sagarmatha zone, East region, Nepal. Location (left) and overview (right).

The area under investigation is characterized by the most complex morphology in the world, and the wind field evaluation is very challenging. CFD methods hardly solve this kind of problems, but can help to understand the main features of the wind field, thanks to indications about the localization of the highest average wind speed, and the trend of energy potential distribution.

3. Materials and methods

3.1. Wind dataset source

Ev-K2-CNR Association, in the framework of SHARE project, provided input data for wind simulation. Ev-K2-CNR, best represented by its Pyramid Laboratory/Observatory located at 5,050 meters a.s.l. in Nepal at the base of Mount Everest, is an autonomous, non-profit association, which promotes scientific and technological research in mountain areas. In 2005 Ev-K2-CNR launched *SHARE project - Stations at High Altitude for Research on the Environment* - with the aim to promote continuous scientific observations in key high-mountain regions, by ensuring the availability of long term and high quality data series. A dedicated tool has been developed to create an international standard catalogue of data and metadata to be used by the scientific community: *SHARE Geonetwork*, a platform for web services based on GeoNetwork open source architecture, available at http://www.share.evk2cnr.org/

In this region a network of six automatic weather stations (AWSs) and one atmospheric laboratory has been installed since 1994 and covers an altitudinal range from 2,660 to 5,700 m a.s.l.; they take hourly measurements of standard meteorological parameters [14].

The Namche Bazar station (27° 48' 8.6" N, 86° 42' 52" E) is located at the Peak Head Quarter and was installed on October 27, 2001. Wind dataset used for this study refers to the period 2001-2010.

3.2. CFD approach and WindSim model

Computational Fluid Dynamics (CFD) is a complement of two approaches, theoretical and experimental. CFD numerical simulations may help to understand even physical experiments. The equations governing the airflow descend from the physical principles: mass conservation, Newton's second law and energy conservation.

Wind modeling of the above-described area was performed through WindSim commercial software, based on a solver for the CFD governing equations. Starting from a series of input data, the different modules of WindSim return several outputs, concerning terrain, wind field and energy produced by the wind farms.

Focusing on terrain model, the roughness height is defined with the log law. The wind fields are calculated with the Reynolds Averaged Navier-Stokes equations (RANS) solution; with a progressive process the flow variables are estimated by progressive iterations. Different models can be used for turbulence such as the k-ε model, the YAP correction, the RNG version or the k-ω. The energy production of the wind farm is calculated using the climate data observed experimentally with ground met-masts and is corrected according to the air density of the site.

4. Results and discussion

The application of the CFD method is based on the evaluation of wind fields in a large area, named the *meso-model*, with a coarse grid resolution of 400 m in the horizontal direction. Because of the influence of the orography, convergence of the model is very difficult, but a good resolution has been obtained. The meso-model calculation results have been used to initialize wind fields in a *micro-model* with a grid spacing of 100 m on the horizontal direction.

The micro model is centered on the position of a met mast. Terrain information were extracted from the ASTER DEM dataset [15], while Global Land Cover 2009 dataset [16] was used for roughness evaluation. Wind database was obtained from the Namche Bazar AWS; the data were filtered with accuracy in order to delete non-physical values and verify good operation state of the anemometer. As said before, results of the meso-scale models were used to initialize wind fields in micro-scale model, where roughness and orography are considered on a refined grid.

In the present study, a local wind map was calculated in order to choose useful positions in the neighbors of Namche; four windy positions were investigated in the neighbors of small villages (Fig. 2).

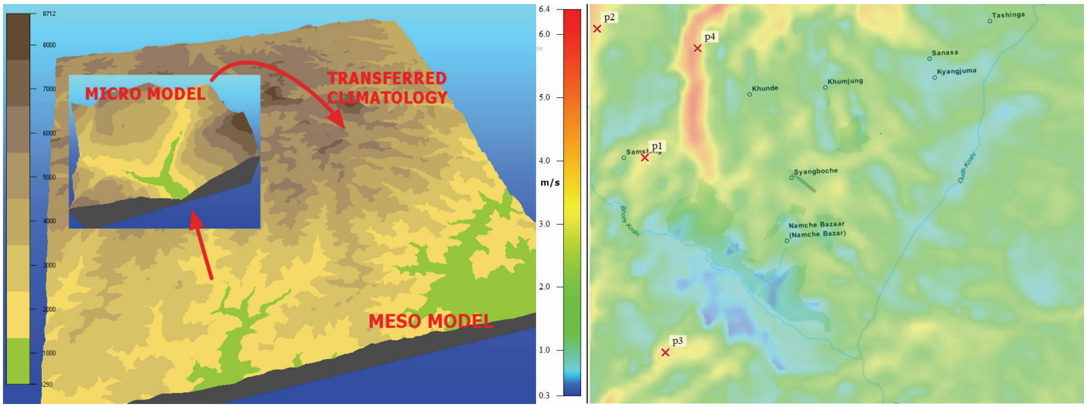

Fig. 2. The calculation domain (left) and the local wind map (right) with the four windy positions, named pX.

The expected wind energy production was evaluated using a micro-wind turbine developed in the Wind Tunnel owned and managed by the University of Perugia, in cooperation with Faist Components SpA. Results were obtained using two different hub heights (10 and 20 m a.g.l.) and particular attention was given on the air density effects. Results are summarized in Table 1.

The air density impact is very strong (around 35% of energy losses), while the effect of hub height is minimal. For P4 position, the amount of energy expected is lower in the higher hub height solution; this is due to the effect of the low value of the cut-out of the wind turbine. The rotor (with an overall diameter of 2 m and a maximum power output of 2 kW) was developed for high efficiency at low wind regimes; this kind of solution is very useful for such remote applications giving meaningful power outputs even in low wind areas. This small turbine is also suitable for remote installation, thanks to its low weight (less than 50 kg) and modular solutions.

		(kWh/year) 10 m		(kWh/year) 20 m	
Turbine	Position x , y (Global)	Standard Density	Density Correction	Standard Density	Density Correction
P1	1061013 , 3089757	1 266.0	834.8	1 505.4	982.2
P2	1060371 , 3091506	1 428.7	882.0	2 209.0	1 398.6
P3	1061296, 3087117	1 318.4	823.4	1 489.4	828.9
P4	1061729 , 3091244	2 194.2	1 362.6	1 302.0	934.7

Tab. 1. Estimated energy production.

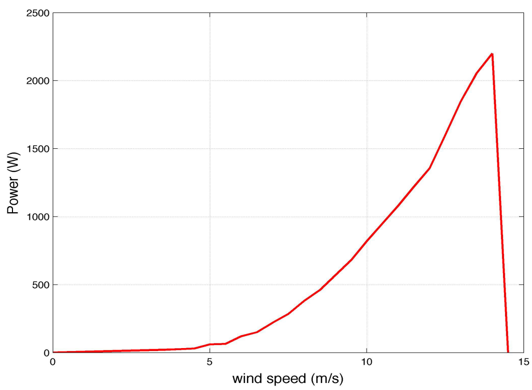

Fig. 3. The power curve of the small horizontal axis wind turbine (2 m diameter).

5. Conclusions

In the integration and smart mini grid perspective, Khumbu Valley and Namche could become one of the first examples of sustainable development at high altitude, a pilot project of international interest about technological innovation for energy efficiency and renewable sources, an effective key action in climate change mitigation extremely important for its repeatability and visibility.

The evaluation of the wind energy potential in a remote region with high orography effects is a difficult challenge, both for calculation convergence and for data availability and accuracy. In this work we used wind data from the Namche Bazar station in order to estimate the possible application of micro wind turbines in this region. Results demonstrate that the possible application of small wind turbines can give a good contribution for feeding the local rural grid addressing, together with other renewable energy sources, the energy demand for local sustainable development.

The overall estimated production (around 1000 kWh/year) for each turbine can be considered an interesting result for the real application of the valuable free energy source.

Acknowledgements

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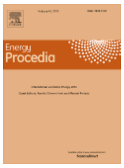
Biography



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