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On the contribution of renewable energies for feeding a high altitude Smart Mini Grid

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HIGHLIGHTS

- Off-grid renewable power generation in a smart mini-grid perspective.
- Direct measurements and CFD simulation for energy resources and consumption.
- Detailed distribution of wind resource in the Khumbu Valley, Everest region, Nepal.
- PV/wind system with storage device, for emergency and permanent scenarios.
- Important wind contribution to the energy balance and positive environmental assessment.

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ABSTRACT

Governments around the world strive to achieve ambitious targets of incorporating considerable amounts of distributed renewable generation and combined heat and power, in response to the climate-change challenge and the need to enhance fuel diversity. The scientific interest is moving toward off-grid power generation systems, based on conventional and/or renewable sources, often coupled with storage devices, which distribute power through a local grid network. This approach, applied to increase electricity access especially in remote areas, is effective to reduce poverty, mitigate climate change and improve the resilience. In this framework, the paper presents the assessment of different renewable sources for power generation in Nepal, aimed to (i) optimize the energy fluxes, (ii) evaluate the long term energy balance by comparing productions and consumption, (iii) preliminary size a multiple input/output storage device on the basis of specific boundary conditions. The study is geographically set within the Khumbu Valley, in the central part of the Himalayan Range, East Region of Nepal, recently damaged by severe seismic events causing serious consequences on population and territory. The specific features of the reference context have been assessed from different points of view, focusing on climate data, energy consumption, and available resources. Wind potential in several spots around Namche Bazar region was estimated using CFD methods, and a customized micro wind turbine – projected by University of Perugia – has been simulated to estimate a hourly production profile. 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 productions from wind turbines and solar PV panels were coupled with household load profiles; a storage system has been preliminary sized accounting technical and logistic aspects, e.g. charge limits of lead acid batteries and portability of the components in extreme conditions. Finally the avoided emissions were quantified in order to evaluate the mitigation effects on climate change.

1. Introduction and motivation

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 that aim at energy saving and use of renewable energies, in a *"rational use of energy"* scenario.

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Numerous technical solutions have been developed in order to save energy, avoid greenhouse gas (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 6000 in 2009 to 17,000 MW in 2015 [1,2]. Governments around the world strive to achieve ambitious targets of incorporating considerable amounts of distributed renewable generation and combined heat and power, in response to the climate-change challenge and the need to enhance fuel diversity. Moreover 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 [3,4]. Off-grid renewable energy resources and technologies (including solar photovoltaics, micro-wind turbines, biomass gasifiers and hydro power plants) can be installed at the local level for schools, hospital or laboratories; these systems could either be linked to an individual household, or connected to a local distribution network [5–12]. 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* [13–15]. This technology occupies a middle ground of electrification options between traditional network extension and individual home systems, with a range of potential benefits (easy to measure, as reduced cost and provision of improved electrical services, or less commonly demonstrated, as social and environmental benefits) and risks (incorrect system sizing due both to energy demand and unpredictable production, challenges related to community integration, equipment compatibility issues, inappropriate business models and risks associated with geographical isolation) [16,17].

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: e.g. for PV systems, while high altitude and low latitude provide increased power production compared with standard locations, the climatic conditions (mainly low temperatures) reduce the real capacity and efficiency of batteries, even if their life span may be extended on long term evaluation. 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 [18,19].

In this framework, present study is focused on the possible exploitation of wind and solar energy potential in the Khumbu Valley. Several points were deeply investigated in order to bridge the current gap of knowledge, especially for the selected high altitude area: (i) distribution of wind resource in one of the most complex orography in the world, strongly affected by variability in time and space, thanks to an accurate study of the anemology and the application of CFD methods; (ii) definition of load profiles, on the basis of a direct audit on energy consumption and available resources; (iii) environmental and economic assessments, taking into account the effects of an unconventional reference scenario, e.g. in terms of transportation. 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 [13,20].

2. Study area

The study is geographically set within the Khumbu Valley, located in the central part of the Himalayan Range. Thanks to its location this valley represents a strategic area to study climate change and its effects on mountain ecosystems, containing the southern half of Mount Everest and its summit (8848 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 increase of human activities and tourism, especially from the end of the 1970s. Moreover 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 (e.g. rooms inadequate ventilation, which is also favored by an architecture that prefers the use of compact rooms with few openings) and obsolete technologies (e.g. stoves are not connected to a chimneypot, so they emit pollutions directly into the room), 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 the forests conservation management, since the 1960s an over consumption of firewood for different uses (building, heating and cooking) contributed to a progressive deforestation and the consequent alteration of the hydro-geological system [21,22]. Moreover heavy exploitation of firewood can also significantly affect both human health, through indoor combustion in poorly ventilated houses, and the environment, due to emissions of Short-Lived Climate Pollutants (as Black Carbon), *i.e.* atmospheric compound able to exert a climate forcing by modifying the energy budget of the atmosphere, but having regional scale and a shorter lifetimes than carbon dioxide.

2.1. Available resources and energy balance

Data collected in two surveys on site in 35 selected settlements along major trekking routes in SNP [21] confirmed that firewood from forests is one of the main energy sources, covering the 30% of demand; kerosene is increasingly used (33%), especially in commercial buildings like tourist lodges and hotels, whereas dung (19%) and liquefied petroleum gas (7.5%) are used less often. Energy is mostly used for cooking (64%, mainly from firewood and electricity, followed by kerosene and LPG) and space heating (23%, mainly form firewood, dung and electricity). LPG, solar thermal systems and electricity are mainly used for heating water (8%) [22].

Renewable energy sources, such as solar, wind, and hydropower, are abundantly 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 no. 6 *hydro*power stations with a capacity ranging from 15 kW to 630 kW plus others pico-hydropowers, providing approximately 7260 kW h_e/day (electric kilowatt-hour per day, *i.e.* 9% of the total energy supplied). The efficiency of existing hydropower systems can be improved through partial or complete rehabilitation, installing better turbines, alternators and controllers as well as by improving civil work components. On average Nepal has 6.8 sunshine hours per day with the intensity of solar radiation ranging from 3.9 to 5.1 kW h/(m^2day), with a commercial potential of solar power for grid connection estimated in 2100 MW. The exploitation of this potentiality will largely depend on the acceptability and affordability of the technology. Small scale *Solar PV* systems are used widely for lighting in Khumbu (10–20 W, 6–12 V and 7–20 Ah battery capacity), especially in