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An Assessment of the Off-Grid Small Wind Power Potential in Nepal

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***Abstract*—Nepal has an abundance of renewable resources, especially in rural areas where energy demand is still overwhelmingly met by traditional biomass. This paper considers the potential for small scale wind turbines (SWTs) to meet the electrical demand of rural communities in Nepal, as assessed through a GIS-based methodology and considerations of the broader enabling environment. Various datasets are processed in order to generate a map of where small wind is estimated to be a viable off-grid technology. The paper also discusses the anticipated barriers and opportunities available to small wind technology.**

***Index Terms*—Sustainable development, Wind energy, GIS, Rural areas, social factors**

I. Introduction

In mountainous regions of rural Nepal it is necessary to consider off-grid generation to meet electrical demand. Grid extension is often technically challenging due to terrain and existing constraints on the grid (highlighted by the recent load shedding crises [1])which make grid extension economically unfavourable in many locations. According to the World Bank, 81% of the population of Nepal live in rural areas [2], and the Global Tracking Framework puts rural electrification rates in Nepal at 82% [3]. National policy documents recognise that clean off-grid energy provision is a requirement for improving the living standards of the rural poor and commit to the long term goal of providing universal access to clean energy by 2030 [4].

The wind resource in Nepal is largely un-utilised at present, with no existing large scale wind farms and few small wind installations. Small wind may be a viable solution for locations where other generation methods are infeasible, especially at high altitudes where wind-speeds are greater. If universal access is to be achieved, no sole generation technology can be expected to satisfactorily meet all demand, and the inclusion of wind power in Nepals energy mix, may be instrumental in helping it reach its energy access targets.

Deployed in the right context, small wind (wind power in the region of 0.5-5kW) can substantially contribute to rural electrification programmes as evidenced by the success seen in Inner Mongolia in the 1990s [5]. The state-sponsored programme in Inner Mongolia targeted rural subsistence farmers and herdsman in areas where where grid extension was not considered to be economically feasible due to large transmission distances and low demand, which would appear to be similar in principle to the situation that exists currently in rural Nepal. The purpose of this work is to assess whether the conditions observed in locations across Nepal match well with the requirements of small wind technology, and suggest where in Nepal small wind technology is most likely to be successful and sustainable.

II. Access to Energy

Access to energy has long been recognised as a necessary condition for human and economic development to take place. The United Nations have enshrined universal access to clean energy as one of the 17 Sustainable Development Goals (SDGs), expanding on the commitments made in the Millennium Development Goals, and many national governments are increasing their commitments to renewable energy technologies and rural electrification programmes [6]. The inefficient use of traditional biomass fuels in developing countries, coupled with the urban concentration of modern energy infrastructure, means that the expansion of existing centralised infrastructure will be insufficient in many cases. Sustainable and decentralised generation is required to enable the rural poor to engage in productive activities and empower themselves [7]. Special attention to rural electrification is required, with rural areas typically home to the poorest people in developing nations and rural electrification rates consistently lower than urban rates [8].

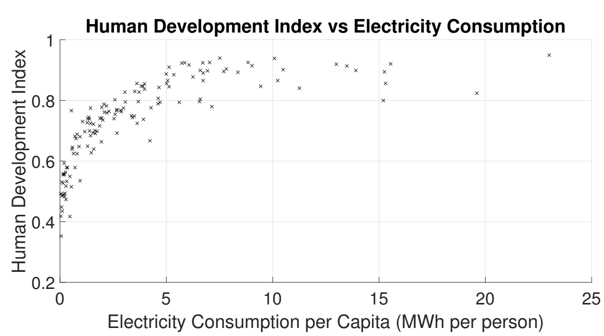

Figure 1. The observed relationship between electricity consumption per capita [9] and HDI [10].

Figure 1 shows the relationship between energy consumption per capita and human development index. It can be seen that at low levels of consumption a small increase correlates well with a significant increase to human development, providing evidence for the hypothesis that the provision of basic energy access enables development.

Nepal remains a medium development country by UNDP classification, with a HDI rank of 144 out of 188 countries [11]. The Asian Development Bank reports that the unavailability of Nepal's infrastructure, along with a lack of affordable and reliable electricity supply, has been a major constraint on development in the country [12]. Given the difficulties faced in meeting current demand, large scale grid extension would first require a marked increase in generation capacity in order to satisfy current demand before any consideration is given to any additional connections..

Off-grid micro-hydro plants have proven the potential for locally managed renewable energy generation to stimulate local economies in Nepal [13] through generation of employment opportunities and local retention of the value chain. It is anticipated that local manufacture, maintenance and management of other Renewable Energy Technologies (RETs) will have a similar effect, although whether locally manufactured SWTs are preferable to commercial turbines in this context requires careful consideration.

III. State of Small Wind in Nepal

A. Renewable Energy Technologies

In Nepal, traditional fuel such as firewood, agricultural residue and animal dung continue to dominate as energy sources. The Alternative Energy Promotion Centre (AEPC), is a semi-autonomous government agency under the Ministry of Population and Environment. The AEPC actively promotes renewable energy technologies such as solar PV and thermal, micro and mini hydro, efficient biomass and biogas technologies across Nepal.

Thanks to the abundance and ubiquity of hydro resource (an estimated exploitable potential of 44,000MW [14], Nepal has seen extensive use of micro-hydro power systems (MHPs) for off-grid rural electrification. As of May 2016, Nepal has an estimated installed capacity of Micro/Mini-Hydro capacity of over 30MW across the country [4]. Micro hydro is, however, probably the most geographically constrained form of renewable generation. Generation potential is determined by the head and flow rate of the river, and sufficient room is required nearby for the turbine housing or for a penstock, where required. Not all rural villages will have access to a stream with the features required for a successful MHP, and indeed some villages will be subject to a seasonally varying power capacity (due to melt-water from the Himalayas and monsoon rains). In these circumstances other forms of generation will be required to provide year round access. Government subsidy policy recognises the dominance of MHPs, paying subsidies to other generation types only where grid extension is not possible in the near future, and where there is no feasibility for micro-hydro [4].

Off-grid solar PV was first implemented in Nepal in 1989 [15], but significant private investment was not seen until the mid 1990's when state subsidies, and other financial drivers, for PV installations were introduced following the formation of the AEPC. An estimated 15MWp of PV capacity is installed in Nepal [16], with Solar Home Systems (SHS) being the most common form of installation. Subsidies are currently available for SHS systems in locations without access to the national grid (or other renewable resource), and a reduced subsidy available for locations with intermittent access to the grid.

B. Small Wind

The first instance of wind power being employed for large scale electrical generation in Nepal was in 1989 in Kagbeni village, Mustang District [17]. Two 10kW turbines were connected with battery storage to the village for electrification, but after less than 4 months both turbines had suffered catastrophic structural failure due to strong winds. This installation should serve as a cautionary tale, providing evidence for the need for a rigorous pre-installation site assessment, but instead has resulted in a lasting damage to the reputation of wind power in Nepal. Nevertheless, there have been efforts to develop the small wind sector in Nepal, with Practical Action Nepal conducting 15 small wind installations across the country between 2001 and 2015. A survey commissioned by AEPC in 2012 showed that a total of 26.7kW is generated by 24 SWTs across Nepal [16], proving the potential for SWTs in Nepal and demonstrating the relative underutilisation of the technology at present.

Subsidies for wind installations were introduced by the AEPC in May of 2016 [4] in an attempt to recognise the nascent wind market, but have had limited impact in encouraging developments thus far. Despite these efforts and due to a range of factors, wind energy remains in its infancy in Nepal. The aim of this study is to provide context for the continued development of small wind in the country.

IV. GIS Processing

A. Establishing an inclusion zone

The method described here was based partly on the work done by IRENA for their 2016 technical report 'Suitability maps for grid-connected and off-grid solar and wind projects in Latin America' [18]. An inclusion zone was established by considering the conditions necessary for successful off-grid small wind installations. The inclusion zone is defined as an area encompassing all locations where SWT's are potential solutions to rural electrification. The selected necessary conditions for a SWT installation site are as follows:

- Sufficient wind resource must exist to allow adequate generation
- Sufficient demand for off-grid electrification must exist
- There must be no obstructions to the turbine, to avoid damage from turbulence
- The land at the site must be suitable for supporting tower and tethers

These are not the only conceivable factors which contribute to a location's suitability for off-grid small wind, but rather reflect the most basic criteria on which siting decisions are made. In order to differentiate between locations in accordance with these criteria, geo-spatial datasets were collected for relevant factors.

1) Wind data: Simulated data for annual average wind speed, at a 1km x 1km resolution and at 50m above ground, was obtained from the Global Wind Atlas, a collaborative project between the Technical University of Denmark and World Bank Group [19]. Given that typical SWT hub-heights vary between 10m and 15m, and that frictional effects reduce wind speeds closer to the ground, wind speeds at hub-height for most SWT's will be lower than the simulated wind speed given in this wind map. Locations with annual average wind speeds equal to, or below, 4.5m/s (at 50m) were excluded on the basis that wind-speeds in this region would be likely to be insufficient for appreciable year-round energy generation with a SWT at a hub height between 10m and 15m. A map of the inclusion zone established by this criteria is presented in Figure 2, where the included areas are highlighted. The wind resource is patchy in the lowland plains of the Terai, with the exception of the south of the Rupandehi District and along the Indian Border between Janakpur and Biratnagar. The most significant wind-resource is found in the foothills and mountains of the Himalayas.

2) Electrification data: Composite satellite imagery of the night-time surface of the earth [20] was used in order to assess the electrification situation across Nepal. The average brightness observed within urban boundaries [21] across South Asia was calculated and used as a threshold, above which a location is considered to be sufficiently electrified. These electrified locations were combined with a buffer area of 7.5km around national grid lines as obtained from open-source maps of the national grid in Nepal [22]. This value was tuned based on population data and night-time satellite imagery. It is assumed that all areas within the features, or within the 7.5km buffer, are currently electrified or can be expected to be prioritised for grid connection. As such all areas within the buffer are excluded on the assumption that any energy needs will be best met by investment in grid generation and extension. A map of the exclusion zone is shown in Figure 3, with the areas assumed to be grid connected shaded in red.

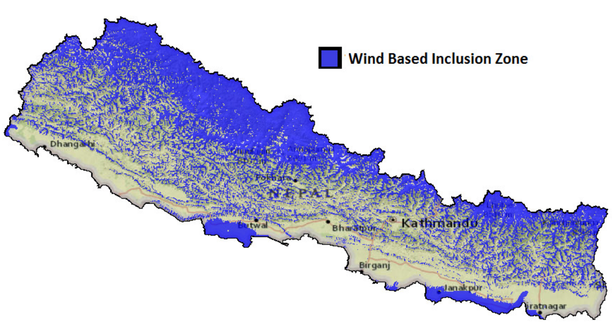

Figure 2. Areas highlighted are inside the inclusion zone established by the simulated annual average wind-speed.

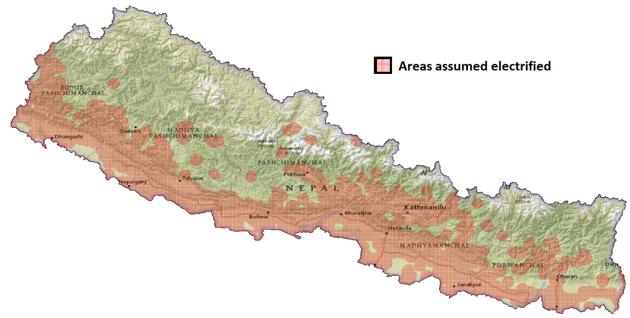

Figure 3. Electrification exclusion zone. The population within the shown area is assumed to have access to the national grid, or be best served by grid extension within the near future.

3) Topography and Orography: Land cover data [23], generated through satellite imagery by categorising 1km x 1km cells into 20 different types of land cover, was used to remove unsuitable land cover from the existing inclusion zone. Forest, wetlands, snow/ice(year round) and urban areas were removed (although through the previous process the majority of urban areas were already excluded).
Elevation data was used to exclude areas based on altitude. All areas above 4800m were excluded, based on the knowledge that the highest operating small wind turbine is installed in Peru at a height of 4877m [24]. Whilst wind-speeds typically increase with altitude, there are fewer people living at these heights, and hard to reach mountaintops are unsuited to sustainable SWT installations due to the inaccessibility for installation and maintenance.

4) Final Inclusion Zone: After combining all these criteria, a buffer of 1km around the generated inclusion zone was made. This was done in order to account for some of the uncertainty in the measured and simulated data used (which had a resolution of 1km x 1km), as the intention is to generate a map of *all* possible suitable locations for SWTs. The final inclusion zone is shown in Figure 4.

B. Results from within the inclusion zone

The World bank gives Nepal's electrification rate as 84.9%, this gives a figure of approximately 24.22 million people with access to electricity living in Nepal and 4.3 million without. The calculated population living within the electrification exclusion zone (given in red in Figures 3 and 4) is 22.46 million, making the calculated value an underestimation of around 7% with respect to the World Bank figure. As the grid data used does not include low voltage transmission lines, and is otherwise likely incomplete, this estimate is considered reasonable, as populations connected to these missing lines will have been omitted from the calculation.
The population within the inclusion zone (according to UN

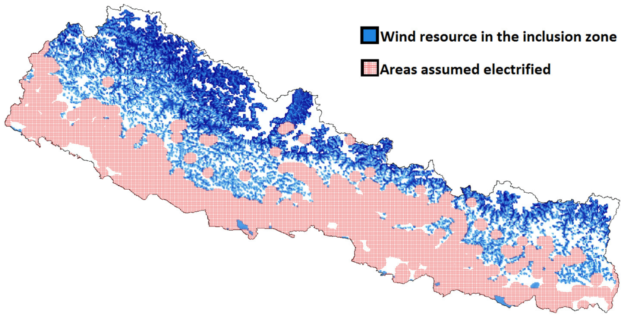

Figure 4. Map of wind resource within the final inclusion zone and the electrified areas exclusion zone. Areas left blank are excluded for low annual average wind-speeds, altitudes greater than 4800m or unsuitable land-cover (eg forests).

data [25]) was calculated to be 3.5 million people, representing the number of people who can potentially be provided electricity through the utilisation of small wind turbines in Nepal.

This is approximately 81% of the 4.3 million un-electrified people in Nepal. It should be noted that this is not the population for which small wind is the optimal generation type, only an estimate of the number of people that reside in areas expected to exhibit some potential.

Accessibility is clearly an issue for off-grid installations in Nepal, with inaccessible installations being markedly more expensive to install and maintain based purely on transportation costs. The mean travel time (according to [26]) to locations within the inclusion zone, from cities of population 50,000 or more, is approximately 15 hours. Maintenance costs in remote areas could be reduced by using more reliable systems, or by establishing a local maintenance hub to reduce the mean time to repair.

C. Limitations of the GIS Inclusion Zone Methodology

The maps produced here serve as a high level estimation of where in Nepal is potentially suitable for small wind turbines for off-grid electrification. It is likely that there are many households within the electrification exclusion zone that are not electrified, and many households outside of the exclusion zone that are electrified. These maps are intended as a high level indication of where one should start investigating when planning SWT installations.

The wind map used is produced by the DTU, using WAsP software to simulate annual average wind-speeds in a 1km by 1km grid. A key limitation of the process used to generate this wind map is its difficulty in making accurate predictions for mountainous terrain - clearly a limiting factor for rural Nepal. Nevertheless, this wind map is the highest resolution and most accurate wind map available for Nepal, another map with 5km by 5km resolution was produced by the SWERA project [27] by AEPC and Risoe-DTU in 2005. The rough terrain and complex orography of Nepal makes individual resource assessments necessary at any prospective site, to ensure the viability of any installations. The wind data used here is insufficient for more localised studies given the relatively large resolution, limitations of the wind model and height at which the data is simulated (50m). The accessibility data used to calculate the mean travel time within the inclusion zone is for the year 2000. The broad inaccessibility of rural Nepal will not have changed greatly in the interim, but infrastructure will have undoubtedly changed, with new roads being constructed and older roads decommissioned.

V. Opportunities and Barriers

A. Absence of reliable wind maps and national assessments

The wind resource in Nepal is difficult to predict given the roughness of the terrain in most of the country. The global wind map used here has been valuable, but the modelling used to generate the annual average wind-speeds is limited in its accuracy in mountainous areas [28]. The SWERA report, released by the AEPC and UNEP in 2006, makes use of ground measurements in 5 sites across Nepal to generate an interpolated map, assuming that the speeds measured at different sites are correlated, which due to the complex topography of the country may not necessarily be the case. The High Asia Refined Analysis (HAR) 10km resolution data was recently compared with observed data across 14 sites in Nepal and found to be some correlation between measured and predicted values, although the modelled values were found to me almost entirely an overestimation of the observed wind-speeds [29]. A large number of wind measurement stations are required, at different altitudes and at different heights above ground level. A national wind resource mapping project has been announced by AEPC, for publication at the end of 2018. It is hoped that the provision of accurate and representative wind-maps will allow for more confident wind project planning and stimulate the wind energy sector in Nepal. A reliable wind map will allow greater confidence when conducting individual feasibility studies and may help secure investment.

B. Increasing confidence in SWTs

In order to have a successful wind energy programme of a reasonable size, confidence in the technology needs to be increased. This may be achieved by ensuring high quality installations are carried out in areas of proven wind resource, augmented with other generators (such as solar PV) in order to ensure year-round operation and reliable energy access. A small number of successful, high quality installations may be sufficient to encourage risk-averse investors to engage with the technology.

C. Certification and standards

AEPC is the key agency for development of guidelines and standards related to renewable energy technologies, including micro hydro, solar PV and end uses. There are ongoing developments focused on grid connection and hybrid systems. Based on the feasibility of small wind turbines, AEPC should focus on developing standards as well as guidelines related to operation and maintenance along with promotional activities to enable market opportunities for local manufacturers. This may enable the successes seen by other RETs to be emulated by SWT installations in future.

D. Maintenance Requirements

Projects implemented through the AEPC require operation and maintenance obligations from the installation contractors. After the termination of the service period from the contractor, the obligation is handed over to the community. The sustainable operation of the plants depends on many factors and requires a viable business operation model, real tariff rates, warranty periods of equipment, etc., before communities become capable of running the plants successfully and independently.

E. Local Manufacture

Activities such as pre-assessment studies and installations are called for by AEPC through a national tender framework, which requires products to be certified to international standards such as the IEC. When this is not the case, projects cannot make use of the given product (for example the Piggott Turbine [30]). This limits the potential of locally manufactured SWTs in Nepal, as relatively high failure rates due to poor construction have been observed in the past. Despite the associated issues, locally manufactured turbines may have the capacity to address technical sustainability issues with service provision at lower costs compared to commercial SWTs. With appropriate certification and testing centres for SWTs, some guarantee of quality can be provided and the risks of poor quality and short-lived locally manufactured devices mitigated.

VI. Conclusion

This paper has discussed an inclusion zone based GIS methodology for highlighting regions predicted to be suitable for off-grid small wind implementation, and considered the political and regulatory opportunities and barriers facing the technology in Nepal. Further work is required to assess the economic basis for small wind installations, and to better map the rural electrification ecosystem. As such, a national market assessment is planned for small wind turbines in Nepal, to better map the enabling environment for SWTs in Nepal and make recommendations for future use of the technology in the rural electrification context.

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