# United Nations Environment Programme
# Global Environment Facility

## Solar and Wind Energy Resource Assessment in Nepal (SWERA)

# Final Report (GIS PART)

Submitted by:

**Alternative Energy Promotion Center**
**Government of Nepal**
**Ministry of Environment, Science and Technology**
**Khumaltar, Lalitpur, Nepal**

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Executive Director
AEPC

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# Executive Summary

Alternative Energy Promotion Centre is the National Executive agency of the Solar and Wind Energy Resource Assessment (SWERA) project under the Government of Nepal, Ministry of Environment Science and Technology in Nepal.  SWERA project is first of its kind in Nepal which has focused into resource assessment of solar and wind energy situation of the country. AEPC is also an apex body of the Government of Nepal working for promoting and disseminating renewable energy in the rural areas of Nepal. It has number of programs and projects and has been promoting alternative energy technologies such as micro-hydro, solar, improved cooking stoves, water mills and biogas. These renewable energy technologies have been promoted under the demand basis and feasibility study for such based on GIS is not yet implemented except for micro-hydro programs. GIS can be used as effective tool for the actual demand and potential for harnessing these energy technologies in different geographical areas.

SWERA has necessitated the importance of GIS to estimate resource assessment for the development of solar and wind energy in the country by developing the GIS based assessment and GIS toolkit development. Unfortunately GIS toolkit development has not been completed in Nepal as expected. None the less the database developed through SWERA and the GIS based analyses to assess wind and solar energy potential will help the private sectors, government and public to develop realistic energy policies and programmes that are based on sound knowledge of available renewable energy resources.

The final report of the SWERA has been already submitted to SWERA/ UNEP which has detailed information about ground measured data and methodology of the analysis of solar and wind energy assessment and comparison of ground measurement data with satellite data. This report contains the GIS part which has been conducted with the help of technical support by TERI under the financial support of SWERA/UNEP and GEF. It is believed that this report and database will help to enhance the knowledge for the researchers and interested investors and will definitely help for further development of solar and wind energy assessment and increase their confidence towards increasing investment in this sector.

GIS based map, for the wind resource assessment, such as wind power density map at 50 meter height is based on Karlshrue Atmospheric Mesoscale Modelling and Wind Atlas Analysis and Application Program (KAMM/WAsP) provided by Risø National Laboratory, Denmark. Similarly, database used for solar resource mapping can be categorized as follows; for concentrating solar potential assessment, the solar direct normal irradiance (13_Solar_direct.shp from DLR) is used while for the Grid connected integrated solar power potential assessment, Global tilt solar irradiance (12_solar_tilt.shp from NREL) is used and for the assessment of the solar remote PV potential of Nepal, Global horizontal solar irradiance (14_solar_global from DLR) is used. GIS based solar irradiance map are acquired from the SWERA Archive.
Further, Forest coverage map, protected area map, national grid transmission line, slope area map, population density map and districts and international boundary map of Nepal are additional input used for the analysis. Concentrated solar power assessment map  has 10 km resolution(from DLR), grid connected integrated PV system assessment map has

40 km resolution map ( from NREL), remote PV potential assessment is carried from map of 10 km resolution ( from DLR) ,for solar water heating system potential assessment , 40km resolution map ( from NREL) is used. The analysis has highlighted the grid connected and isolated solar potential of Nepal. Similarly the certain mountainous and hilly districts have the great potential of the wind energy harvesting to utility scale. There are definitely certain places in the Nepal with large wind and solar power energy potential but this assessment basically focused on the area within 15 km buffer zone from existing Nepal Electricity Authority (NEA) national Grid line. 15 km buffer zone was taken for the analysis because normally densely populated urban and sub urban area within aforementioned buffered range from NEA Grid and shorter transmission line increases viability of the large project.

Nepal Electricity Authority (NEA) has the peak electricity demand about 912 MW (NEA, 2007) whereas more than 912 MW could be generated only from wind power plant. The analysis shows that 3000 MW of electricity could be generated from wind energy with consideration of 10% of area with more than 300 $W/m^2$ WPD. Similarly if 2% of the area taken as suitable for the power generation there is possibility of about 1830 MW from the concentrating solar power which is more than power demand of NEA and there is also a possibility to generate about 2100 MW from grid connected PV if power generation per square kilometer is considered to be 50 MW with 2% of the land area as suitable for power generation.

# Solar and Wind Energy Resources Assessment Based on GIS

## 1.1 Background

Global warming is one of the most challenging serious and debated issues in the world today. The sky rocketing demand and massive dependence on fossil fuel for the energy needs (mostly consumed by developed nation) has destroyed the climate of the world adversely. So it is high time to increase the ratio of renewable energy in total energy supply. Green renewable energy such as wind, solar, hydroelectric system and even in bio mass energy is the highly potential alternative of the fossil fuels. This green energy not only curbs the effect of the global warming but they are the only energy solution for the future generation after the fossil fuel is depleted to zero level.

Nepal is one of the under developed countries in the world economy scenario but in terms of renewable energy, it is one of the richest countries. Nepal has hydro electric energy potential only after the Brazil in the world. But most of the energy demand is fulfilled from the forest products and fossil fuel with very few portions from the renewable energy. In addition solar and wind energy could be the milestone in the renewable sector after hydro electric for the harvesting the energy at the time that price of the fossil fuel is sky rocketing daily. Especially, Nepal having a weak economy definitely needs to implement renewable energy technologies to meet its energy demands as soon as possible. Nepal has great potential for the renewable energy and because of the difficult topography and scattered settlement, solar and wind energy can be one of the best alternative energy solutions for the remote area of Nepal.

Solar photovoltaic systems, solar photovoltaic water pumping systems, solar thermal water heaters are some of the solar technologies that have been used in the country. Also, solar thermal space heating and illumination in buildings are already in practice. Total capacity of solar PV system in Nepal has reached 4.3 MWp by the end of December 2007[1]. Similarly, several solar thermal technologies, such as solar water heating systems, solar dryer, solar cookers are being installed in different parts of Nepal. There is possibility of large-scale development in solar and wind energy technologies in near future in the country. At least for now today, we have the solar and wind resource maps highlighting the potential districts or area for the solar and wind harvesting. Definitely we are now in the situation that we can plan and implement what type of solar plant development is feasible such as concentrating solar power, grid connected PV system, water heating PV system and Remote PV for lighting in particular area.

## 1.2 Objectives

General objective of this study is solar and wind energy resource assessment of the country and its specific objective is to develop methodology for energy resource mapping; develop database and base resource maps for energy planning as well as to provide information on the solar and wind energy resource potential in Nepal.

[1]Report on Status of Solar PV sector in Nepal ,AEPC/ESAP- July 2007

# 2.0 Solar Energy Assessment and Methodology

Solar Energy Assessment has been carried out for Concentrated Solar Power (CSP), Building Integrated Photovoltaic System and Solar Water Heating System for the grid connected urban area and Photovoltaic for the remote area isolated from grid connection. The assessment focuses on the different area with viability of different mode of renewable energy. Following SWERA database have been used for the overall analysis of the solar energy potential area:

- Direct normal irradiance in kWh/m$^2$/day (13_solar_direct.shp)
- Global tilt solar irradiance in kWh/m2/day (12_solar_tilt.shp)
- Global horizontal solar irradiance in kWh/m2/day (14_solar_global.shp)

## *2.1 Additional data for the analysis*

The additional data that were used in the process of analysis are as follows:

- Forest coverage map of Nepal
- Protected area map of Nepal
- National Grid Transmission line
- Slope area map of Nepal (>45$^o$ slope)
- Population density map (based on projected population of Nepal for 2006)
- Districts and International Boundary map of Nepal

## *2.2 Maps and Projection system*

All the maps used on the analysis are based on the projection system Modified Universal Transverse mercator with origin of central meridian 84º. Different maps with different projection system were projected into the mapping system of (Modified UTM-84) Nepal for analysis. Central meridian for the projection system is taken 84º for whole Nepal instead of three meridian used by survey department ( 81º for western part, 84º for middle and 87º for Eastern part of Nepal) so that any block of map loaded aligned in GIS system. Detail of Projection parameters is given below:

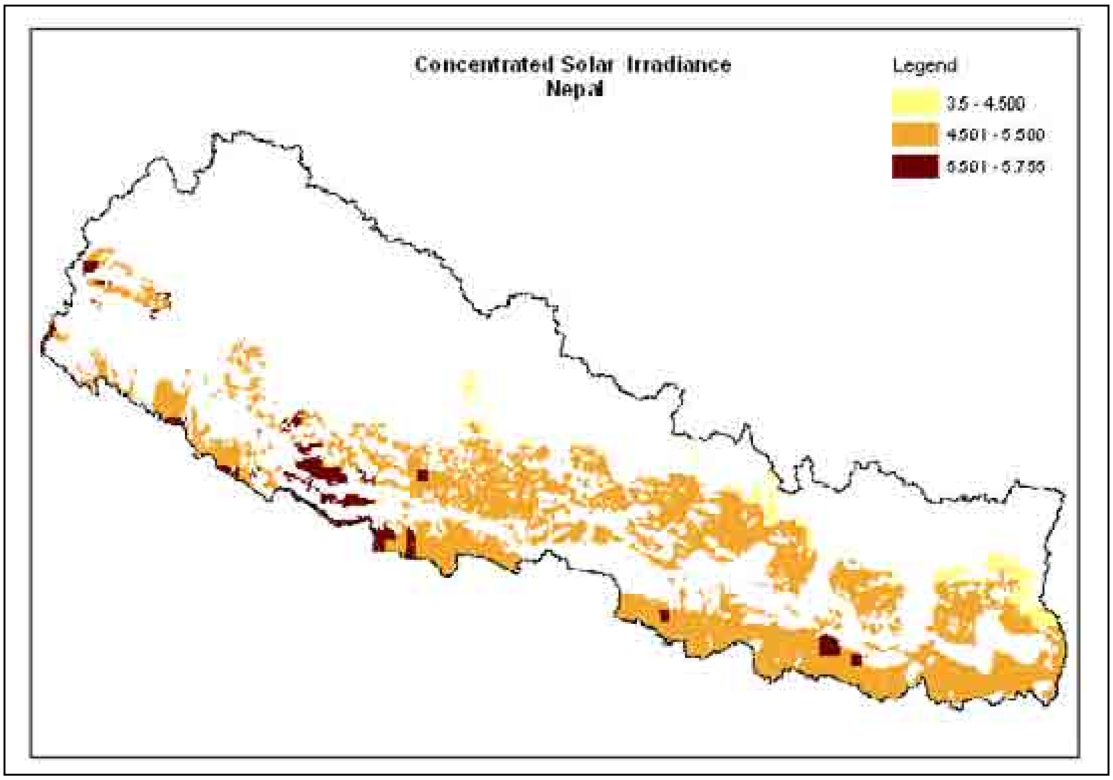
<u>Horizontal Datum</u>

| | |
|---|---|
| Spheroid | Everest 1830 (Adjustment_1937) |
| Projection | Modified Universal Transverse Mercator |
| Origin | Longitude 84º East, Latitude 0º North |
| False Co ordinate of Origin | 500000m Easting, 0m Northing |
| Scale factor of central meridian | 0.9999 |

# 3.0 Concentrating Solar Power (CSP)

The concentrated solar power assessment has been carried out using 10 km resolution direct normal irradiance in kWh/m2/day as base data. For this analysis, area within 15 km buffer of existing transmission lines has been demarcated as the potential area for CSP development. Buffered area of 15 km is taken on assumption that those areas are connected by the transmission line and thus it is possible to feed the generated power by CSP to national grid. From the buffered area, some non exploitable areas for the CSP are excluded. Such area are national parks, forest, steep area (slope> 45$^o$) and densely populated settlement with population density greater than 5000 per square kilometer. In this analysis, water bodies are not taken into consideration due to less significance in area as a whole. Transmission lines are based on the data from NEA prepared in the year 2000. Densely populated area map was derived from the CBS (central bureau of statistics) projected population data 2006 which was converted into raster data in GIS system and population density map was prepared from the aforesaid population data. Population density more than 5000 per square kilometer area has been buffered 2 km for the exclusion from the potential 15 km buffered area. Figure 1 shows the concentrated solar power potential available in Nepal excluding the aforementioned area of 15 km buffered from the transmission line greater than 11kV. According to this analysis, Nepal has obtained about 37501 sq km area that falls under CSP potential which is 25% of the total area of Nepal.

*Figure1. Concentrated Solar Power potential for Nepal (kWh/m2/day)*




Considering high concentrating solar radiation is required for power generation from the CSP, area under average annual irradiance >5.5 kWh/m$^2$/day is taken which is about 2729 sq.km. Typical solar trough technology produces 33.5 MW peak per sq.km of land area. If only 2% of the best solar irradiance is taken for the power generation, it can yield 1829 MW which is more than the present power demand 912 MW of Nepal(NEA, 2007). If cost for building such plants comes at competitive price then there will be huge demand for solar energy for the coming year and that will also enhance in clean energy development.

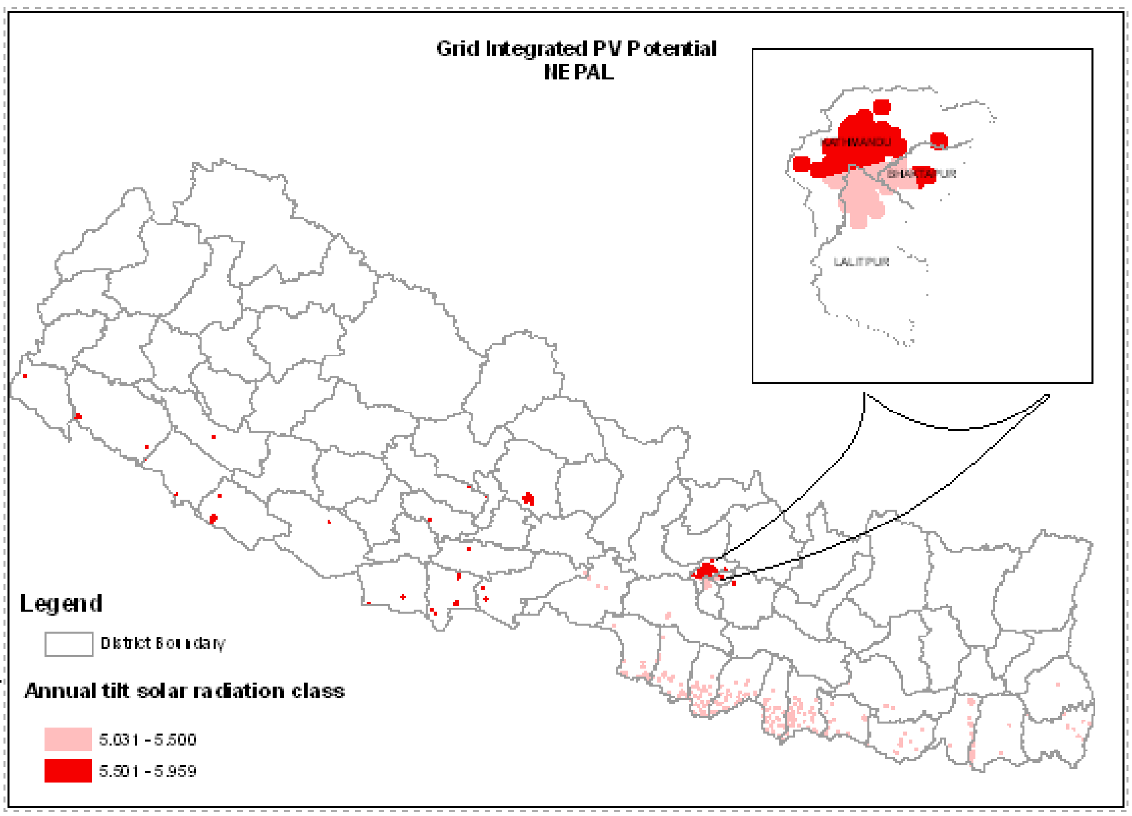
*Table 1 Area under different annual direct normal radiation in Nepal*

| S No. | Solar Radiation Class(kWh/m$^2$/day) | Average Annual Radiation(kWh/m2/day) | AREA(km$^2$) |
|---|---|---|---|
| 1 | 3.5 - 4.5 | 4.16 | 2174.49 |
| 2 | 4.5 - 5.5 | 5.22 | 32597 |
| 3 | 5.5 - 5.75 | 5.561 | 2729.53 |
| | Total | | 37501.02 |

## 4.0 Grid Connected Integrated PV

The exploitable PV that can be connected to grid has been assessed by using the global tilt solar data at 40km resolution. Grid connected integrated PV system analysis area has been considered in areas with dense population. For the analysis, urban areas with population density greater than 3500/ sq km have been considered as threshold. Cities with population density greater than 3500 were buffered 1km for analysis area delineation  Figure.2 shows the grid connected integrated photovoltaic potential of Nepal.

*Figure 2 Grid connected integrated PV potential of Nepal*



| S No. | Solar Radiation Class($kWh/m^2/day$) | Average Annual Radiation(kWh/m2/day) | AREA($km^2$) |
|---|---|---|---|
| 1 | 5.0 - 5.5 | 5.28 | 1724.5 |
| 2 | 5.5 - 5.96 | 5.67 | 443.48 |
| | | Total Area | 2167.98 |

Grid connected integrated PV potential was calculated in the urban area. If power generation per sq. km is considered to be 50 MW and 2% of the land area is considered as suitable land, then an area of 2167 sq. km could yield 2100 MW. So the exploitable area for grid integrated PV potential is significantly high in Nepal. From Table 2, it can be seen that high solar radiation (>6.0 kWh/m2/day) location are not in the urban areas.

## 5.0 Remote PV

For Remote PV potential mapping, global tilt radiation with 10km resolution has been used. In the analysis, remote area has been considered as those areas where there is no grid connectivity and those areas have been excluded from 10 km buffer distance from existing grid lines (including 11 kV line) while for the isolated small hydropower area, only 2 km buffer distance has been used. Those areas have been considered as not connected by grid. Protected areas, forest coverage, steep terrain area (slope>$45^o$) have been removed from the remaining area and population data for the remote areas has been calculated from the population density map of the final map. Population without grid and isolated grid has been estimated from final data.

Figure 3 shows the area available for the PV potential. It has to be noted that about 28789 sq. km area of Nepal is not connected to the grid and population in those area are expected as 24789. In this estimation, non electrified area seems lower than actual figure of remote area because protected areas having settlements and settlements within the buffer distance of 10 km which have no access to the national grid yet have not been included. Estimated population in the remote area extracted from the population density map based on CBS projected data of 2006 is about 2,411,177.

*Figure 3 Remote Photovoltaic Potential of Nepal*

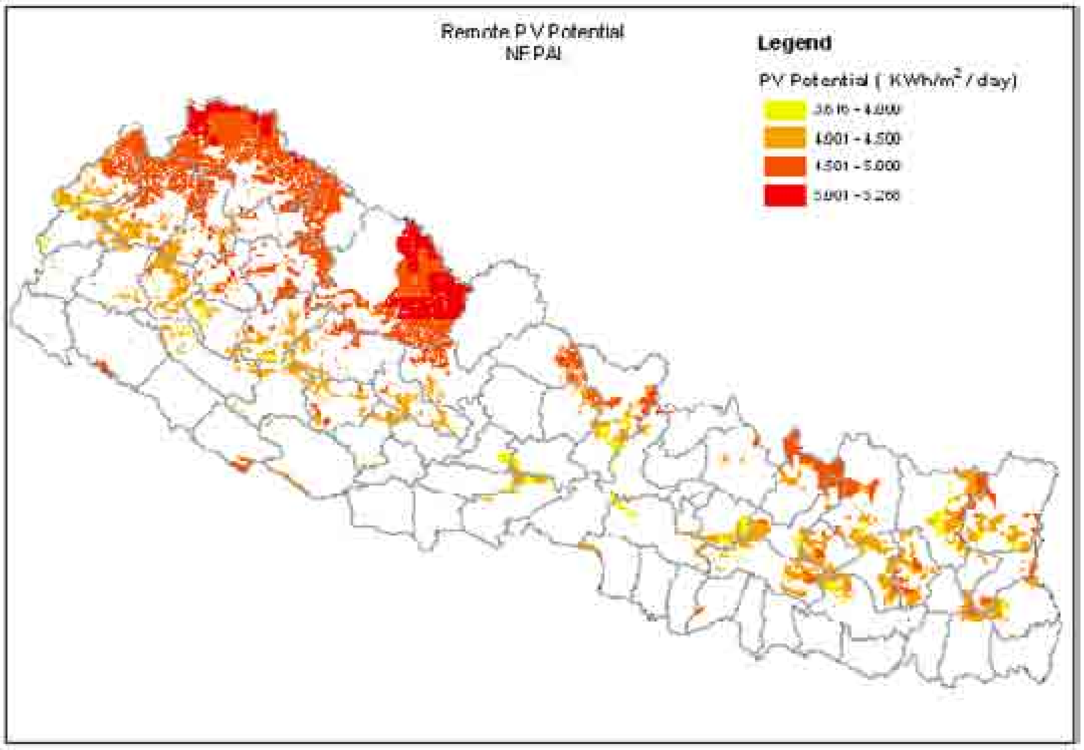



*Table 3 Remote PV potential area without grid connectivity*

| **S No.** | **Solar Radiation Class(kWh/m²/day)** | **Average Annual Radiation(kWh/m²/day)** | **Estimated population(2006)** | **System required** |
|---|---|---|---|---|
| 1 | 3.6 - 4.0 | 3.89 | 385073 | 70013 |
| 2 | 4.0 - 4.5 | 4.26 | 1654989 | 300907 |
| 3 | 4.5 - 5.0 | 4.68 | 368410 | 66983 |
| 4 | 5.0 - 5.28 | 5.06 | 2705 | 491 |
| | | Total | 2411177 | 438395 |

## 6.0 Solar Water Heating System

12_Solar_tilt.shp data with the resolution of 40 km has been used in the analysis of potential estimation for water heating systems of Nepal. In this analysis, only grid connected and densely populated cities of Nepal have been considered. Densely populated cities or towns have been defined as cities that have population density greater than 3500/ sq km. This population density has been considered so that major cities of Nepal; eg Mahendranagar could be included in the analysis. If population density was taken as 5000 then other major cities of the country such as Mahendranagar would not be included in this analysis. Selected areas with population density greater than 3500 have been buffered just 1km to get the city boundary. Population density map was derived from the CBS projected data 2006.

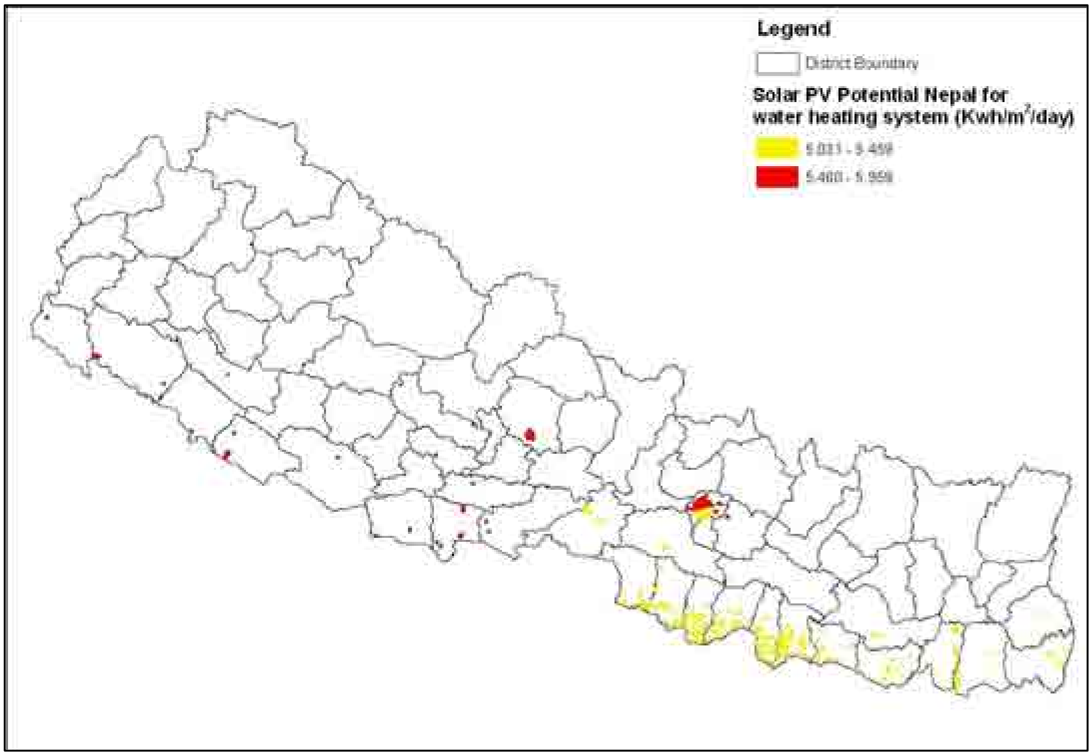
Per capita hot water requirement has been assumed to be 25 liters per day. Then to heat up the amount of water, a system with solar panel of 0.5 sq m is required. Figure 4 shows the suitable area for the solar water heating system development in Nepal while Table 4 shows the number of solar panel systems required as per the population in the corresponding city population.

*Table 4 Area available and required system for the hot water delivery in the selected districts of Nepal*

| S No. | District | Area ($Km^2$) | Average_Annuulal _Radiation( Kwh/$m^2$/ day) | Projected Population _2006 | Area_ Required($m^2$) |
|---|---|---|---|---|---|
| 1 | Kapilbastu | 16.56 | 5.591 | 30667 | 15333.5 |
| 2 | Chitwan | 40.34 | 5.408 | 1110651 | 555325.5 |
| 3 | Rautahat | 210.66 | 5.357 | 252038 | 126019 |
| 4 | Jhapa | 67.12 | 5.08 | 100224 | 50112 |
| 5 | Morang | 77.42 | 5.224 | 222912 | 111456 |
| 6 | Sunsari | 68.67 | 5.302 | 191343 | 95671.5 |
| 7 | Saptari | 74.15 | 5.28 | 97196 | 48598 |
| 8 | Ilam | 8.52 | 5.254 | 10972 | 5486 |
| 9 | Udayapur | 26.91 | 5.288 | 33114 | 16557 |
| 10 | Siraha | 88.31 | 5.333 | 119732 | 59866 |
| 11 | Dhanusa | 261.12 | 5.372 | 365433 | 182716.5 |
| 12 | Makawanpur | 19.49 | 5.32 | 60614 | 30307 |
| 13 | Kavre | 11.14 | 5.607 | 21852 | 10926 |
| 14 | Sindhuli | 0.51 | 5.26 | 71 | 35.5 |
| 15 | Sarlahi | 186.58 | 5.35 | 247274 | 123637 |
| 16 | Mahottari | 192.07 | 5.37 | 247258 | 123629 |
| 17 | Banke | 34.92 | 5.763 | 95794 | 47897 |
| 18 | Dang | 8.14 | 5.779 | 17027 | 8513.5 |
| 19 | Bardia | 15.63 | 5.653 | 24343 | 12171.5 |
| 20 | Surket | 8.14 | 5.959 | 197700 | 98850 |
| 21 | Kailali | 28.66 | 5.625 | 58516 | 29258 |

| | | | | | |
|---|---|---|---|---|---|
| 22 | Kanchanpur | 8.15 | 5.669 | 13168 | 6584 |
| 23 | Bara | 148.04 | 5.311 | 204629 | 102314.5 |
| 24 | Parsa | 100.04 | 5.289 | 227713 | 113856.5 |
| 25 | Laliptur | 62.54 | 5.433 | 309751 | 154875.5 |
| 26 | Baktapur | 40.91 | 5.487 | 175875 | 87937.5 |
| 27 | Kathmandu | 154.86 | 5.586 | 1219606 | 609803 |
| 28 | Ruandehi | 55.38 | 5.571 | 141164 | 70582 |
| 29 | Gulmi | 8.14 | 5.71 | 12465 | 6232.5 |
| 30 | Magdi | 0.18 | 5.689 | 235 | 117.5 |
| 31 | Baglung | 9.84 | 5.672 | 18916 | 9458 |
| 32 | Palpa | 8.46 | 5.556 | 11880 | 5940 |
| 33 | Nawalparasi | 25.28 | 5.477 | 46623 | 23311.5 |
| 34 | Parbat | 5.91 | 5.632 | 9517 | 4758.5 |
| 35 | Kaski | 57.20 | 5.632 | 197377 | 98688.5 |

*Figure 4 Solar water heating potential of Nepal*




# 7.0 Assessment of Wind Resources Potential

Wind resources map has been based on the Risø 50m agl wind potential map of 5 km resolution for Nepal. The analysis of high potential area has been assessed based on the available data and certain assumptions. In this analysis, only the area within 15 km from the existing national electricity grid has been considered as the potential area as there is existence of 11 kV transmission line. This assumption has been made on the basis that power generated from wind farm within 15km of the national grid will be viable for grid connection considering the topography of Nepal. This analysis is basically bounded to the area connectable to the grid .Though there are some high wind energy potential areas in Nepal which are far from the grid, they are not considered in this analysis. Exceptionally, Annapurna Conservation Area, which is one of the protected areas of Nepal, has been considered and analyzed separately provided that there is high demand for electricity as well as high potentiality of wind energy in this conservation area. Very steep and difficult terrain with slope greater than $45^0$ has been also removed from the analysis. Protected, densely populated and forest areas have been removed for the analysis.

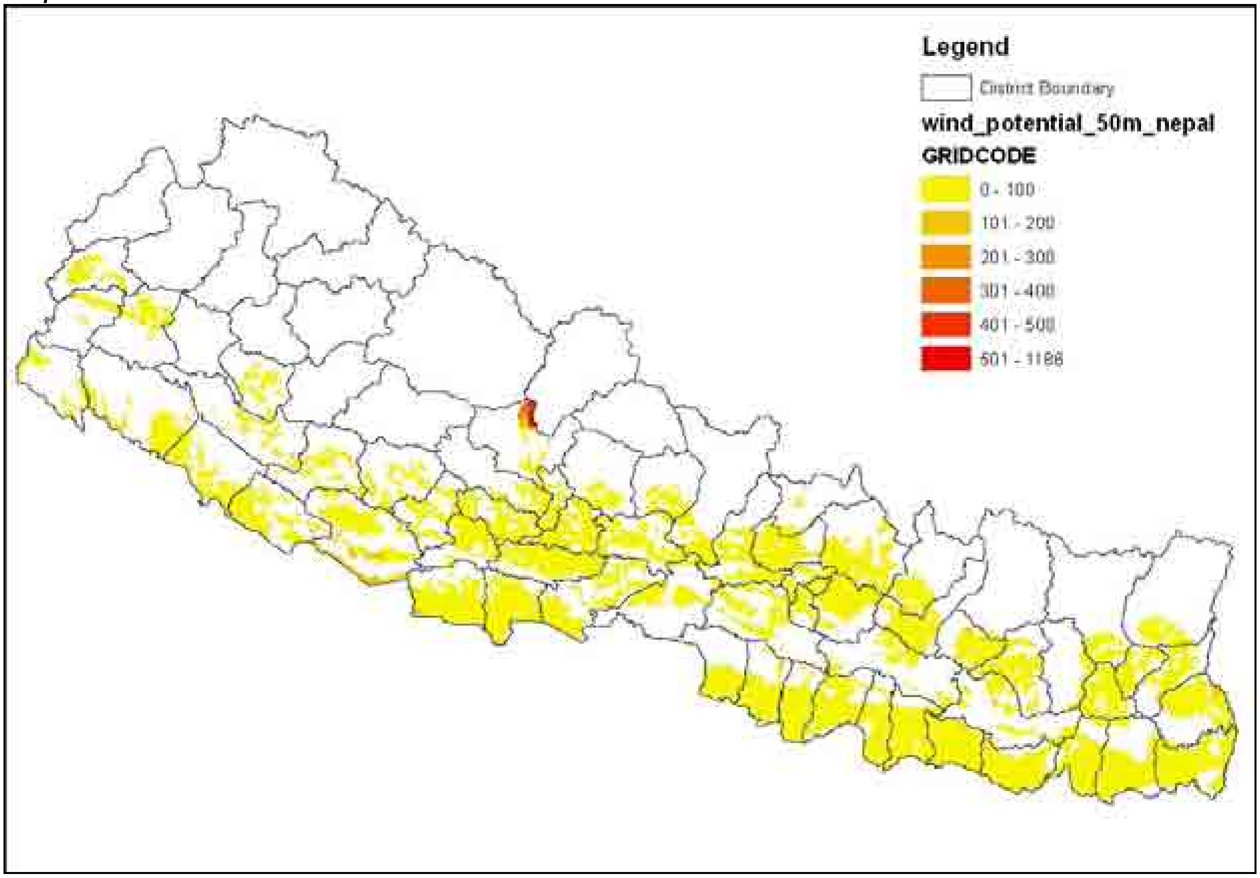
Wind power density less than or equal to 100 Watt/$m^2$ are not useful for wind energy harnessing. WPD greater than 200 Watt/ $m^2$ are normally taken for consideration for non grid connected power generation while greater than 300 Watt/ $m^2$ are considered as grid connectivity wind energy in developing countries. The analysis shows area above 300 Watt/ $m^2$ composed of 97 sq km and with 5 MW installed per sq km, yields 489 MW. These areas have been calculated on a conservative basis so that the exploitable area for wind energy can be increased by covering greater area from the national grid and specially analyzed in specific areas with greater wind energy potential

Table 5 below shows the wind power density classes. Under each class, the total power potential for wind power development has been indicated.

*Table 5 Area under different Wind Power density*

| Wind power density | Average_WPD | Area ($km^2$) | Potential@5 MW/Km2 |
|---|---|---|---|
| <100 | 25 | 37178.08 | |
| 100 - 200 | 124 | 449.86 | |
| 200 - 300 | 217 | 27.74 | |
| 300 - 400 | 353 | 21.99 | 109.95 |
| 400 - 500 | 473.5 | 31.74 | 158.7 |
| >600 | 819.25 | 44.07 | 220.35 |
| Total | | 37753.48 | 489 |

*Figure 5 Wind power potential of Nepal*




## *7.1 Wind Potential Assessment in Annapurna Conservation Area*

Annapurna Conservation Area is one of the famous trekking and tourist destinations in the world. Being one of the famous trekking destinations; demand of electricity for local people and tourist is very high but being a conservation area, it has definitely fragile ecosystem and any man made activity should be limited. Moreover, physical development should be initiated with in-depth research and analysis with regards to ecological, cultural and natural perspective. People in this area still depend upon traditional energy resources; such as firewood kerosene and other petroleum products to fulfill the energy demand except in some potential places where solar and micro hydropower in use for the lightning purposes. In this context it should be noted that Annapurna Conservation Area is one of the high wind energy potential areas of Nepal. Land use pattern shows that barren land and small pasture land are dominant and forested areas are at minority land cover unlike the other national parks of Terai and hilly regions of Nepal where densely forested area are the dominant land cover. Though in international practices, conservation and protected areas are not chosen for wind farming, the ACAP region has a different case. Hence it can be concluded from the aforementioned reason. Wind farming would not only help in conservation of environment and forest but it would help in reducing many environment related problems in the ACAP area. In this way, the protected area can be made pollution free or less polluted by generating wind energy which finally helps in the sustainable development of the area with clean energy in fragile ecosystem region.

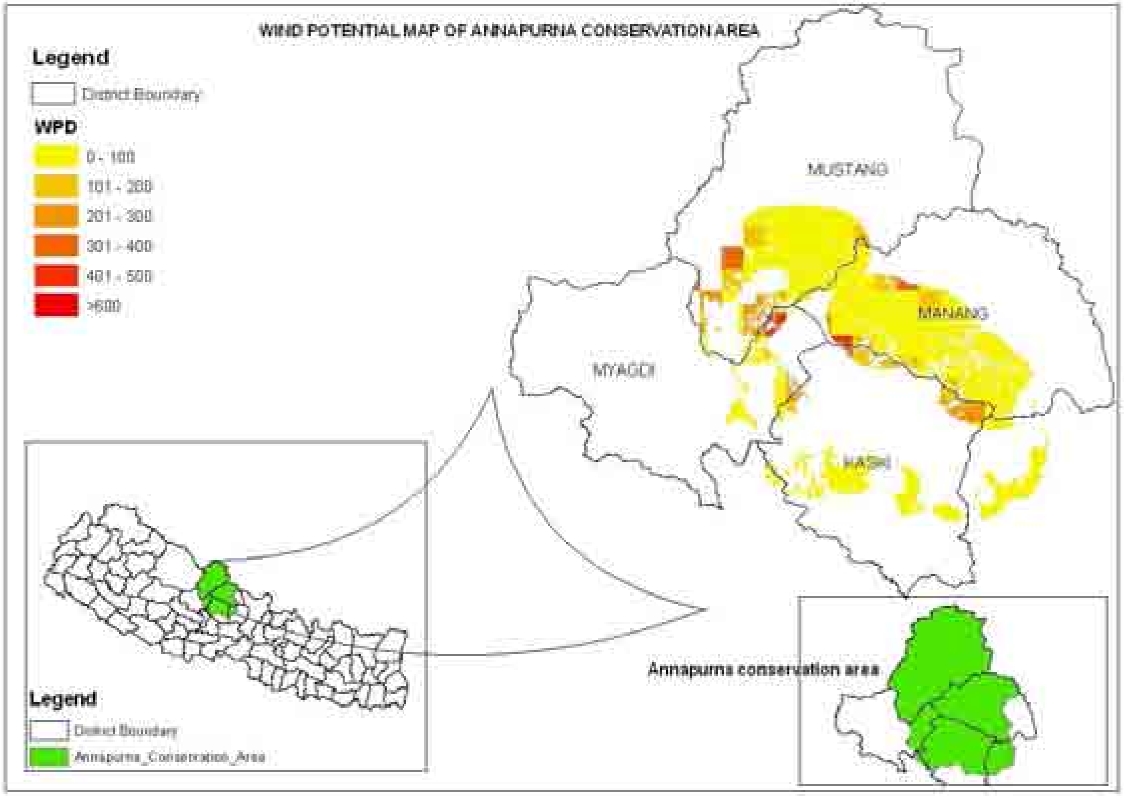
By the analysis, it has found that ACAP area covers 143 sq km above WPD 300 Watt/ $m^2$ and with 5 MW installed per sq km yields 716 MW which is very huge amount in case of Nepal which have very low power generation from green energy source. In this assessment also, wind resource potential mapping has been done in the buffer region of 10km from the existing grid (grid connected wind resource potential mapping) so that the power generated from the wind energy could be integrated into national grid without huge cost of transmission and distribution. If the total conservation area is considered, then the wind energy potential will be definitely much higher than the aforesaid wind power potential.Table5.1. shows the average WPD of the Annapurna Conservation Area.

*Table5.1 Area under different WPD in Annapurna conservation area*

**Annapurna Conservation Area**

| **S No.** | **Wind power density** | **Average_WPD** | **Area ($km^2$)** | **Potential@5 MW/Km2** |
|---|---|---|---|---|
| 1 | <100 | 21 | 1485 | |
| 2 | 100 - 200 | 142.86 | 205.43 | |
| 3 | 200 - 300 | 242 | 13.36 | |
| 4 | 300 - 400 | 318.33 | 35.6 | 178 |
| 5 | 400 - 500 | 437.33 | 30.12 | 150.6 |
| 6 | >600 | 918.4 | 77.6 | 388 |
| Total | | | **1847.11** | **716.6** |

*Figure 5.1 Wind Potential Annapurna Conservation Area*




## *7.2 Gross Wind Potential of Nepal*

By considering commercially viable wind power density (WPD) 300 w/$m^2$, there is 6074 sq. km area with the aforesaid 300 or greater than 300 WPD. If 10% of the area is considered as feasible for wind energy production, then the huge amount of power can be generated from the wind. From aforesaid figure,10% of the 6074 sq. km i.e 607.4 sq. km at the rate of 5 MW per sq. km, 3000 MW of electricity can be generated from wind energy only which is far more greater than electricity demand of Nepal.

*Table 5.2 District wise Annual Average Solar Rradiation and Wind Power Density Database of Nepal*

| S No. | NAME | Annual Direct Solar radiationKwh/ m2/day | Annual Global Solar Radiation(kwh/m2 /day) | Annual Tilt Solar Radiation(kwh/ m2/day) | Wind Power Density(w/m2) |
|---|---|---|---|---|---|
| 1 | ACHHAM | 5.408 | 4.180 | 5.990 | 6 |
| 2 | ARGHAKHANCHI | 5.365 | 4.084 | 5.594 | 19 |
| 3 | BAGLUNG | 4.585 | 4.370 | 5.773 | 19 |
| 4 | BAITADI | 5.372 | 4.222 | 6.097 | 7 |

| S No. | NAME | Annual Direct Solar radiationKwh/ m2/day | Annual Global Solar Radiation(kwh/m2 /day) | Annual Tilt Solar Radiation(kwh/ m2/day) | Wind Power Density(w/m2) |
|---|---|---|---|---|---|
| 5 | BAJHANG | 4.634 | 4.583 | 6.129 | 113 |
| 6 | BAJURA | 4.858 | 4.639 | 6.193 | 33 |
| 7 | BANKE | 5.479 | 4.488 | 5.756 | 53 |
| 8 | BARA | 5.372 | 4.663 | 5.298 | 43 |
| 9 | BARDIYA | 5.465 | 4.469 | 5.777 | 19 |
| 10 | BHAKTAPUR | 4.821 | 4.573 | 5.578 | 9 |
| 11 | BHOJPUR | 4.698 | 4.260 | 5.351 | 15 |
| 12 | CHITAWAN | 5.122 | 4.306 | 5.461 | 7 |
| 13 | DADELDHURA | 5.479 | 4.176 | 5.887 | 8 |
| 14 | DAILEKH | 5.270 | 4.217 | 6.086 | 13 |
| 15 | DANG | 5.561 | 4.271 | 5.692 | 70 |
| 16 | DARCHULA | 4.539 | 4.424 | 6.190 | 112 |
| 17 | DHADING | 4.704 | 4.175 | 5.666 | 28 |
| 18 | DHANKUTA | 5.139 | 4.248 | 5.360 | 26 |
| 19 | DHANUSHA | 5.389 | 4.773 | 5.332 | 45 |
| 20 | DOLAKHA | 4.198 | 4.490 | 5.560 | 127 |
| 21 | DOLPA | 4.650 | 4.924 | 6.359 | 149 |
| 22 | DOTI | 5.421 | 4.236 | 5.886 | 9 |
| 23 | GORKHA | 4.224 | 4.357 | 5.742 | 96 |
| 24 | GULMI | 5.102 | 4.135 | 5.729 | 5 |
| 25 | HUMLA | 4.596 | 4.874 | 6.460 | 203 |
| 26 | ILAM | 4.877 | 4.396 | 5.181 | 40 |
| 27 | JAJARKOT | 5.043 | 4.470 | 6.170 | 16 |
| 28 | JHAPA | 5.274 | 4.774 | 5.110 | 37 |
| 29 | JUMLA | 4.851 | 4.788 | 6.461 | 30 |
| 30 | KABHRE | 4.895 | 4.177 | 5.468 | 35 |
| 31 | KAILALI | 5.445 | 4.357 | 5.683 | 12 |
| 32 | KALIKOT | 5.268 | 4.685 | 6.240 | 17 |
| 33 | KANCHANPUR | 5.505 | 4.448 | 5.684 | 14 |
| 34 | KAPILBASTU | 5.479 | 4.626 | 5.591 | 46 |
| 35 | KASKI | 4.100 | 4.227 | 5.600 | 93 |
| 36 | KATHMANDU | 4.901 | 4.440 | 5.578 | 7 |
| 37 | KHOTANG | 4.860 | 4.270 | 5.303 | 16 |
| 38 | LALITPUR | 4.895 | 4.354 | 5.525 | 16 |
| 39 | LAMJUNG | 4.167 | 4.180 | 5.554 | 72 |
| 40 | MAHOTTARI | 5.348 | 4.691 | 5.341 | 41 |
| 41 | MAKWANPUR | 5.061 | 4.183 | 5.384 | 18 |
| 42 | MANANG | 4.122 | 4.767 | 5.925 | 184 |
| 43 | MORANG | 5.374 | 4.771 | 5.217 | 46 |
| 44 | MUGU | 4.704 | 4.770 | 6.497 | 129 |
| 45 | MUSTANG | 5.021 | 5.063 | 6.379 | 332 |
| 46 | MYAGDI | 4.131 | 4.537 | 5.813 | 176 |
| 47 | NAWALPARASI | 5.262 | 4.365 | 5.527 | 6 |
| 48 | NUWAKOT | 4.786 | 4.191 | 5.722 | 5 |
| 49 | OKHALDHUNGA | 4.852 | 4.267 | 5.371 | 17 |

| S No. | NAME | Annual Direct Solar radiationKwh/ m2/day | Annual Global Solar Radiation(kwh/m2 /day) | Annual Tilt Solar Radiation(kwh/ m2/day) | Wind Power Density(w/m2) |
|---|---|---|---|---|---|
| 50 | PALPA | 5.302 | 3.997 | 5.610 | 7 |
| 51 | PANCHTHAR | 4.578 | 4.308 | 5.328 | 30 |
| 52 | PARBAT | 4.782 | 4.090 | 5.688 | 2 |
| 53 | PARSA | 5.306 | 4.544 | 5.317 | 28 |
| 54 | PYUTHAN | 5.157 | 4.174 | 5.738 | 16 |
| 55 | RAMECHHAP | 4.629 | 4.269 | 5.448 | 64 |
| 56 | RASUWA | 4.569 | 4.884 | 5.777 | 56 |
| 57 | RAUTAHAT | 5.355 | 4.759 | 5.307 | 46 |
| 58 | ROLPA | 4.999 | 4.375 | 5.939 | 25 |
| 59 | RUKUM | 4.702 | 4.508 | 6.038 | 28 |
| 60 | RUPANDEHI | 5.395 | 4.650 | 5.548 | 18 |
| 61 | SALYAN | 5.393 | 4.192 | 5.933 | 28 |
| 62 | SANKHUWASABHA | 3.615 | 4.322 | 5.409 | 240 |
| 63 | SAPTARI | 5.434 | 4.890 | 5.277 | 67 |
| 64 | SARLAHI | 5.333 | 4.741 | 5.297 | 39 |
| 65 | SINDHULI | 5.212 | 4.227 | 5.326 | 19 |
| 66 | SINDHUPALCHOK | 4.233 | 4.337 | 5.735 | 33 |
| 67 | SIRAHA | 5.454 | 4.862 | 5.300 | 56 |
| 68 | SOLUKHUMBU | 3.973 | 4.637 | 5.459 | 354 |
| 69 | SUNSARI | 5.397 | 4.793 | 5.275 | 45 |
| 70 | SURKHET | 5.408 | 4.059 | 5.938 | 13 |
| 71 | SYANGJA | 5.139 | 3.877 | 5.612 | 3 |
| 72 | TANAHU | 5.118 | 3.919 | 5.549 | 3 |
| 73 | TAPLEJUNG | 3.705 | 4.461 | 5.467 | 117 |
| 74 | TERAHATHUM | 4.809 | 4.227 | 5.427 | 4 |
| 75 | UDAYAPUR | 5.345 | 4.446 | 5.304 | 38 |

## 8.0 Conclusion:

This study has come up with wind and solar energy potential maps for Nepal that will help to identify the places in Nepal on the basis of their potential for any of these two energy resources. The maps provided have to come up with better plans and investment to harness wind and solar resources of Nepal. Till date, the solar and wind energy assessment has not been done to this extent. Hence this report shall help and pave the way for the further micro level of the study for wind potential and farming as well and will definitely help in harnessing solar and wind in Nepal.

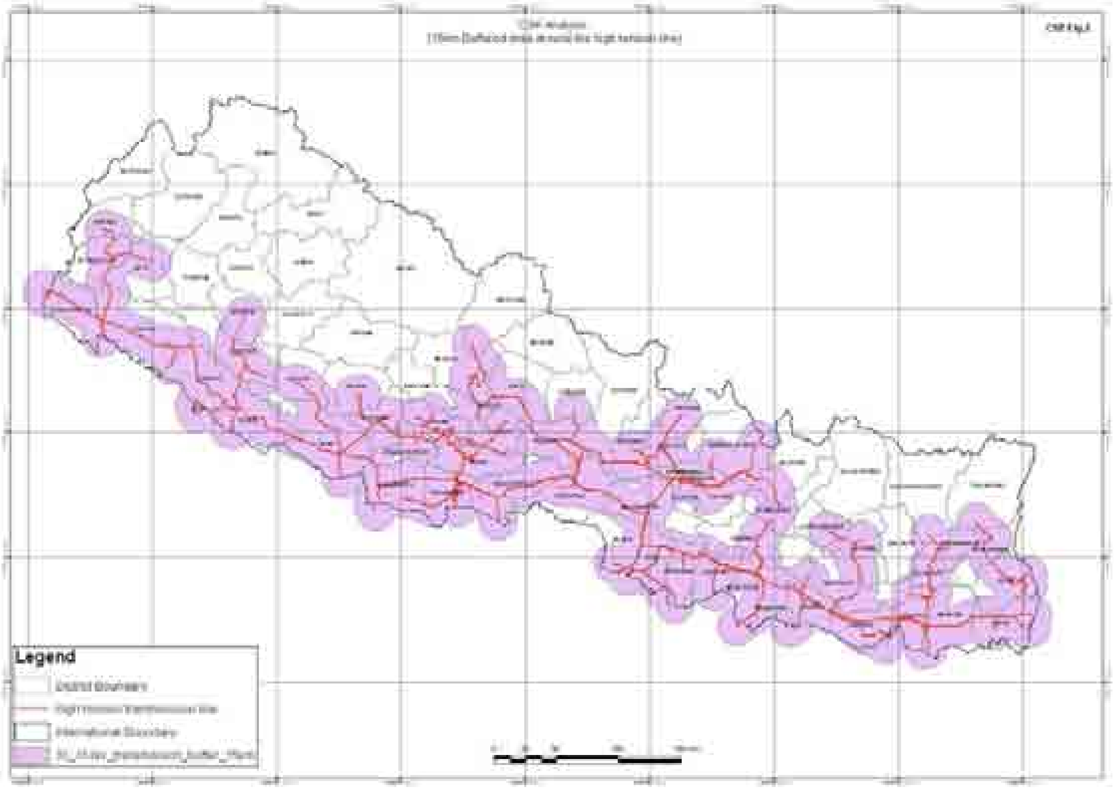
## 9.0 Recommendations

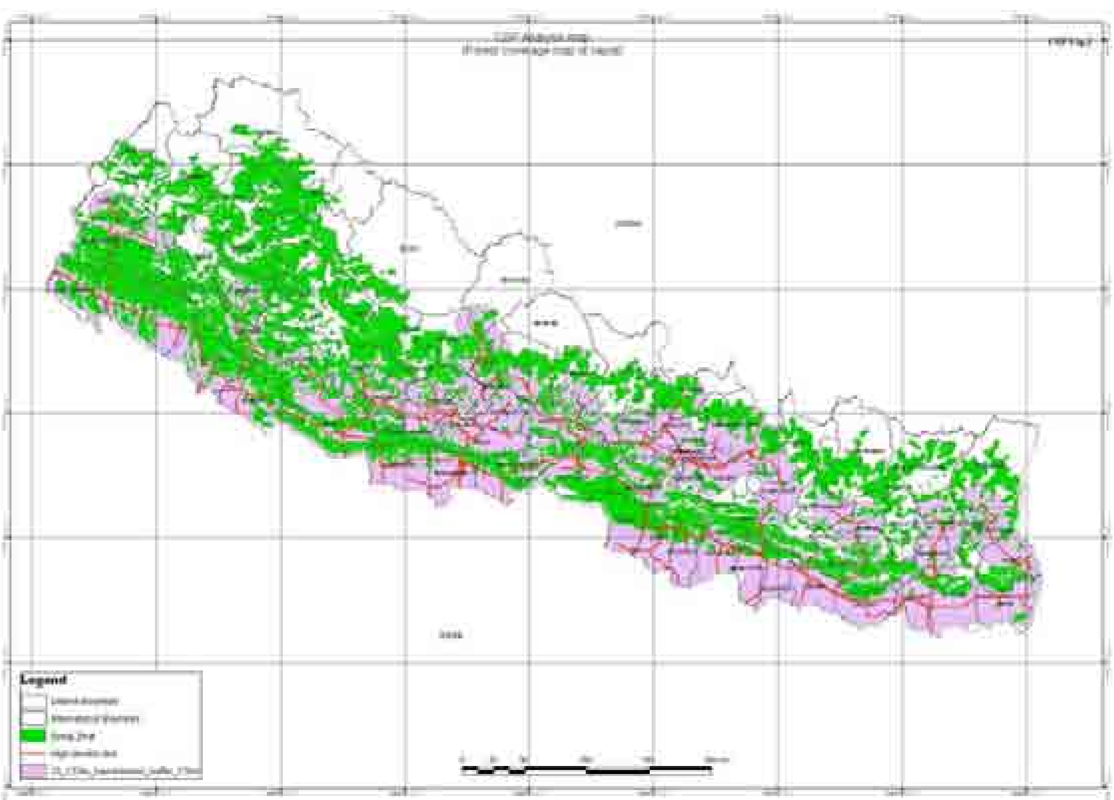
- Further analysis and research is required for assessing the whole and micro-level potential of the solar and wind resource of Nepal.
- Validation of the mesoscale modeling is required
- Training and upgrading of the related software is required.
- Since the country has limited number of data measurement station, Preference should be given to expand the station network in the country in order to fine tune the modeling.
- Due to the topographical variation of the country micro level of modeling is required for wind energy resource assessment.
- Since the study has shown good solar potential at most places in Nepal, it is wise to apply wind-solar hybrid system at places which do not have consistent wind flow and generated electricity should be used for off grid systems and moreover, places with high wind energy should be connected to the grid and that could save the water used to produce electricity from high dam projects such as kulekhani hydro electricity projects during windy part of a day.
- Since there is no need of high wind speed for the small wind turbines, small system less than 400 watt could be installed to electrify the rural areas without long term data.

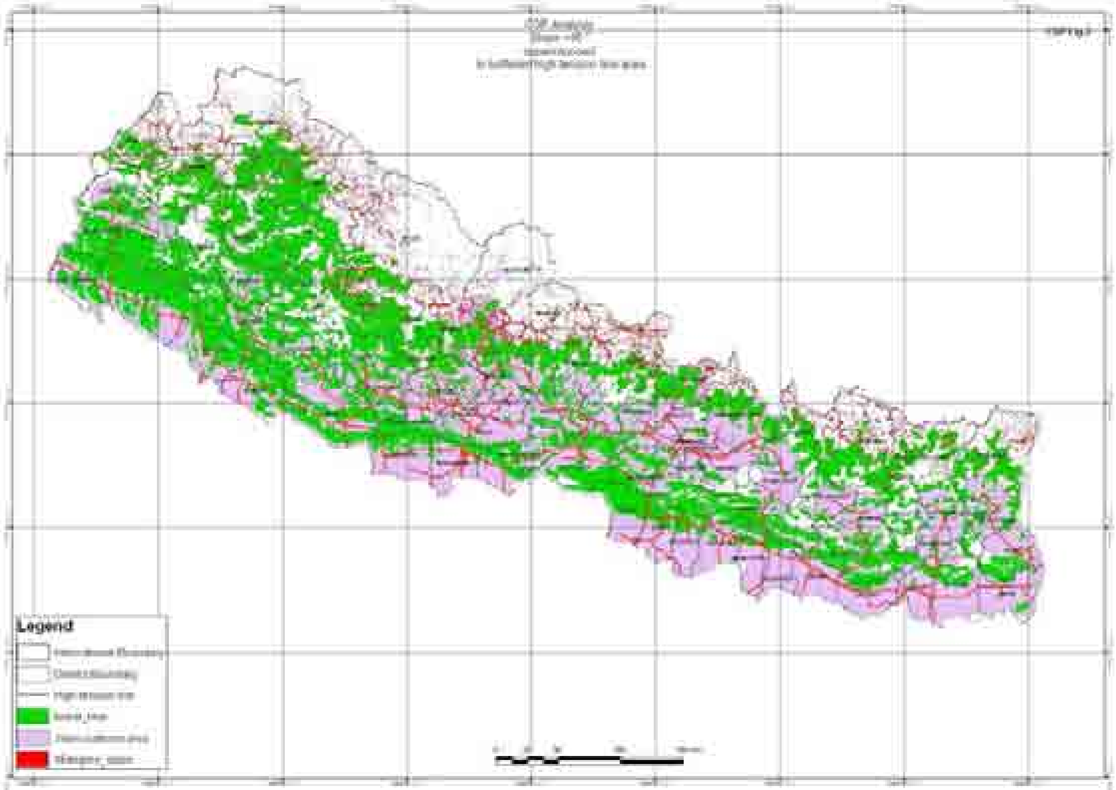
# ANNEX

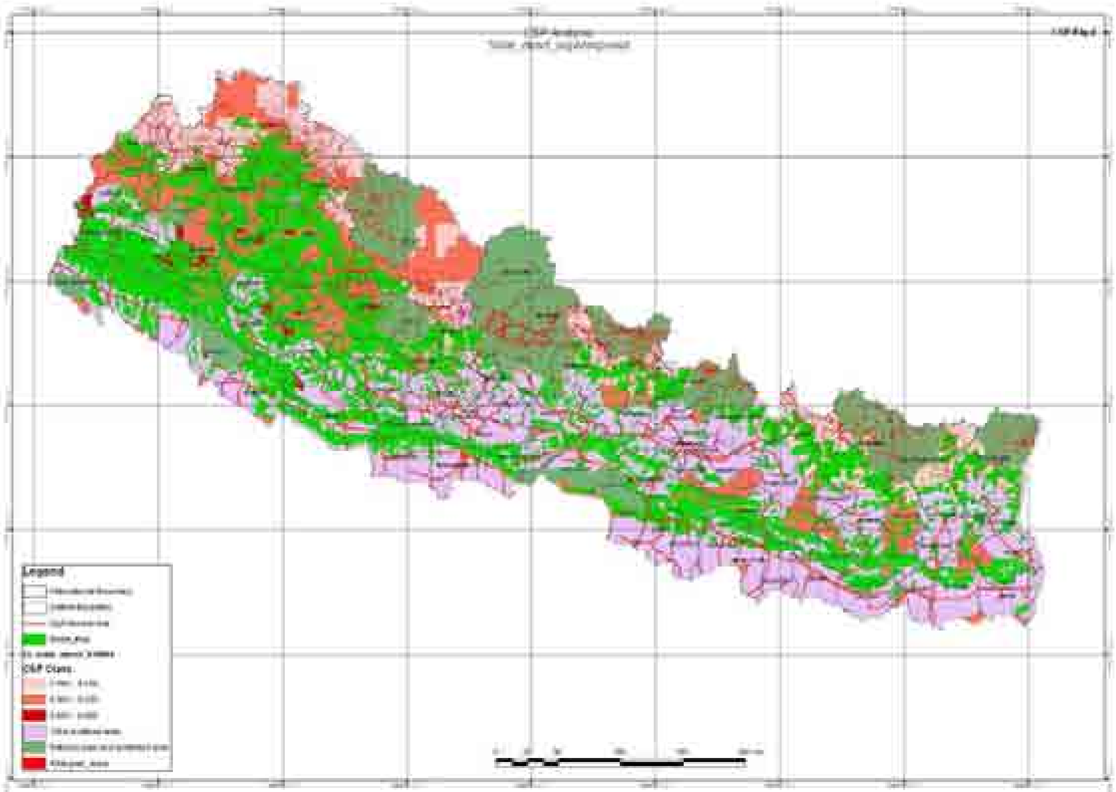
# *ANNEX-1*

## *Concentrating Solar Potential Analysis Maps*


Legend


Legend


Legend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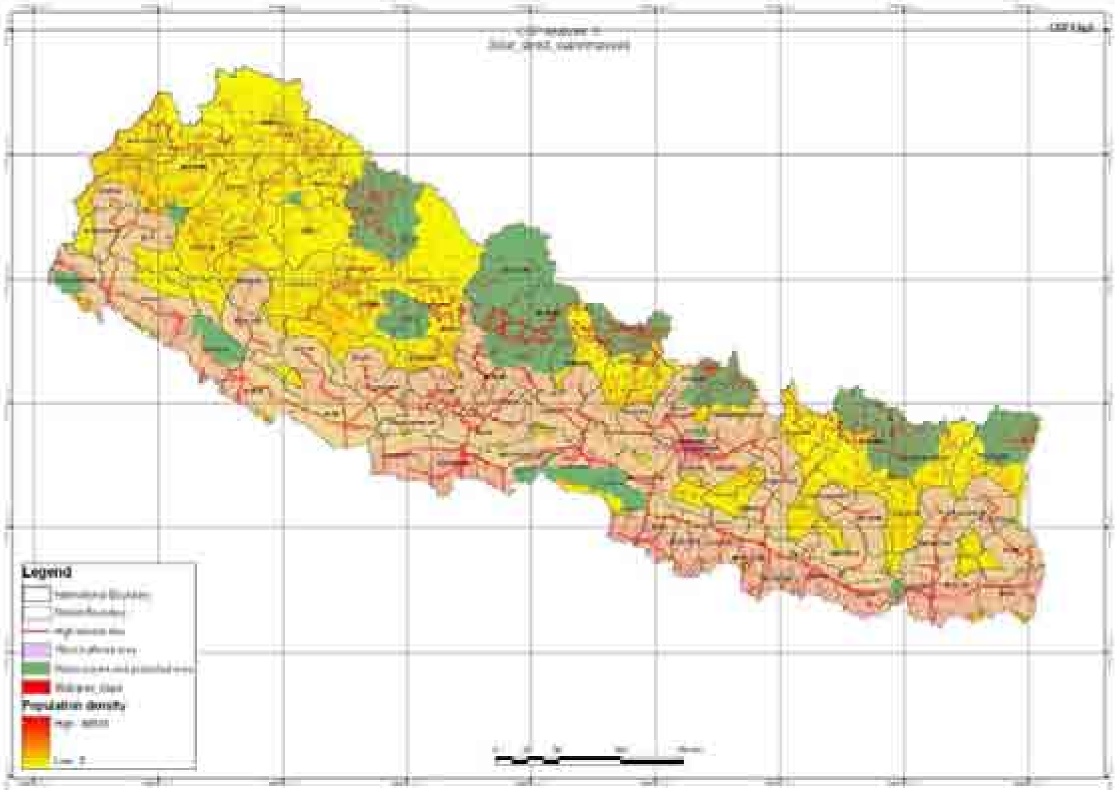
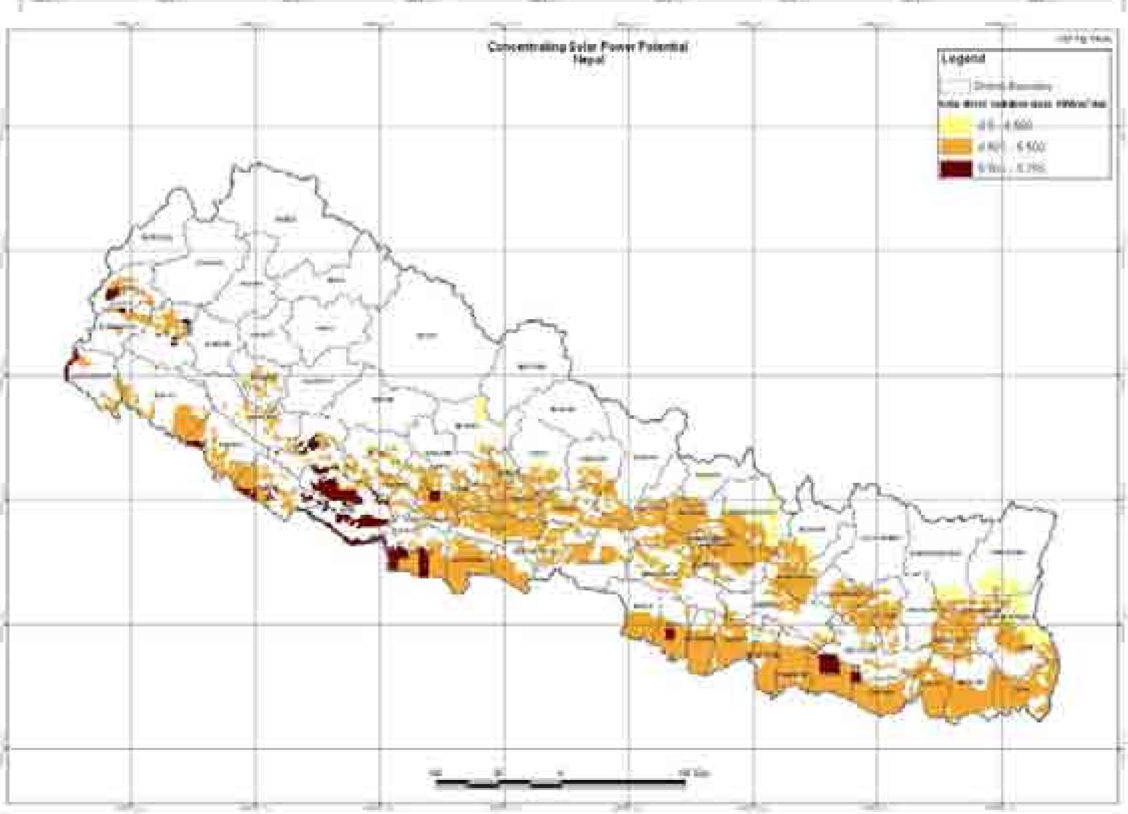
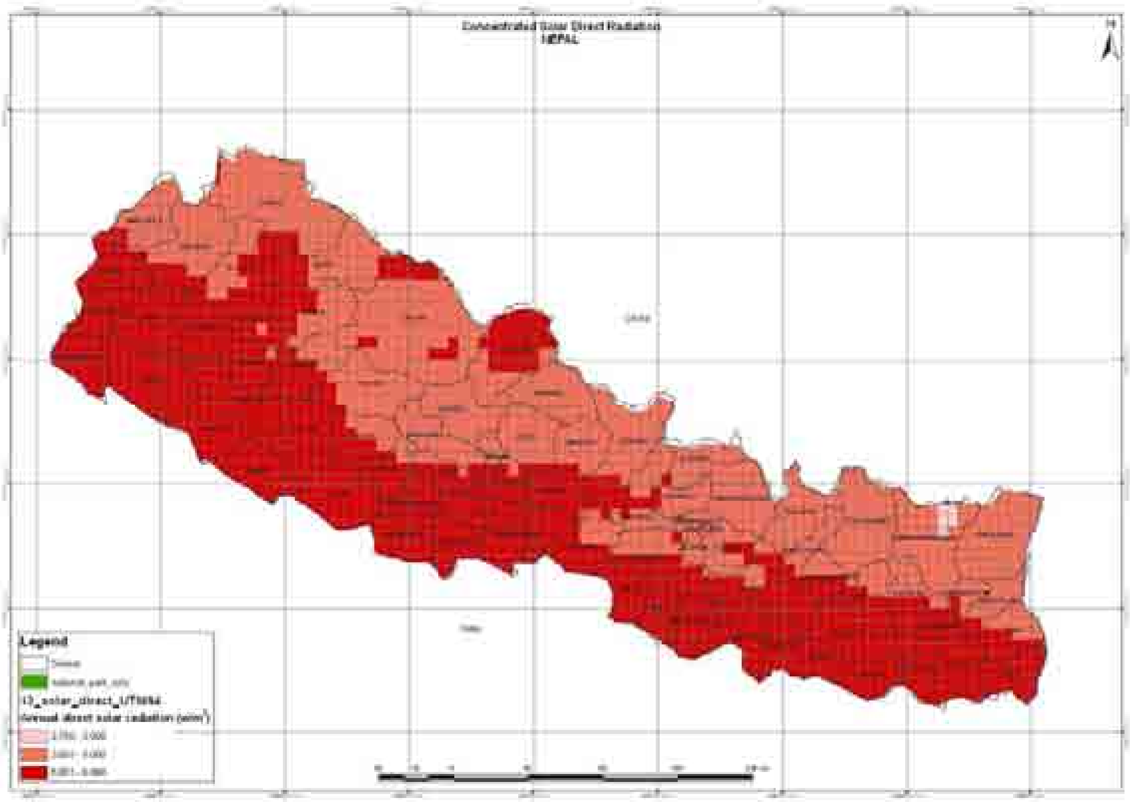

Legend
Population density

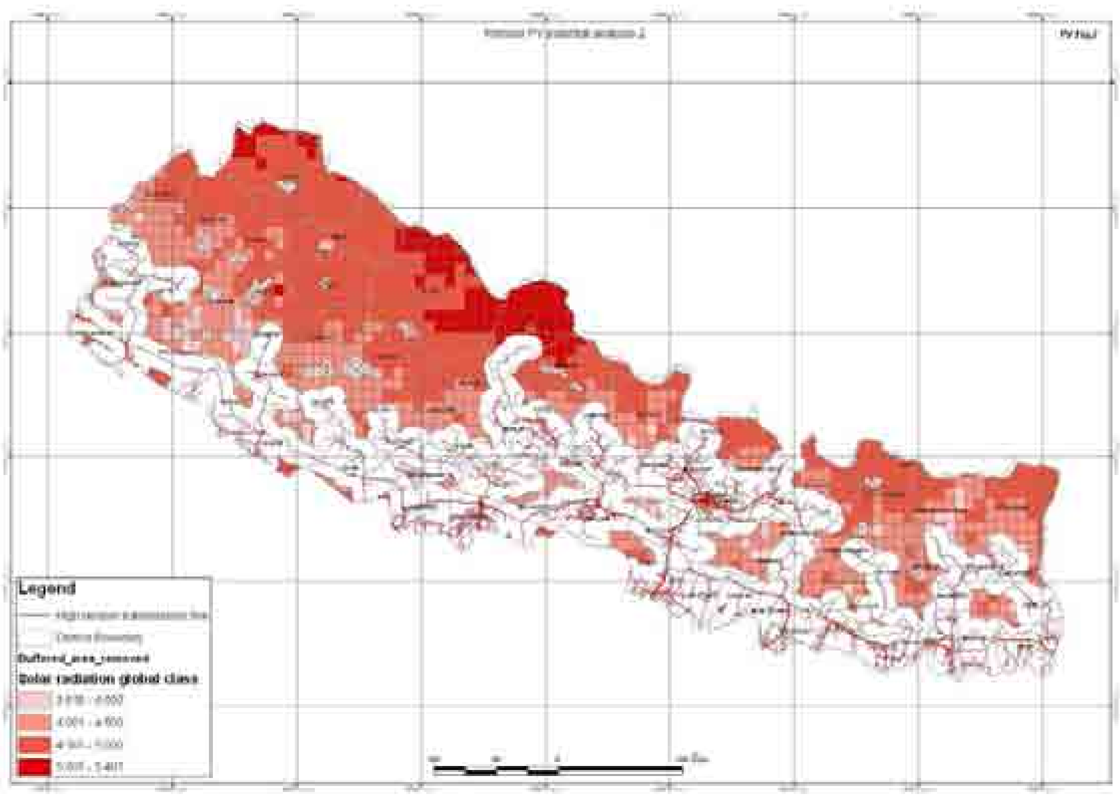

Concentrating Solar Power Potential
Nepal
Legend

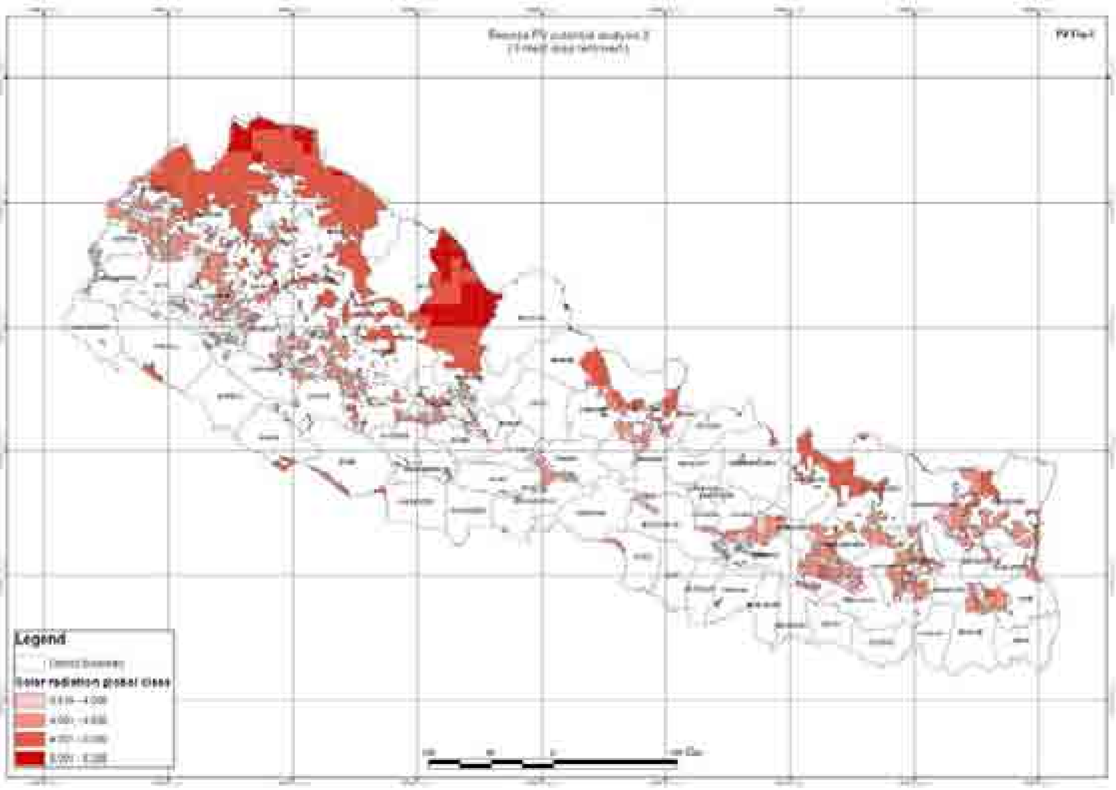

Concentrated Solar Direct Radiation
NEPAL
Legend

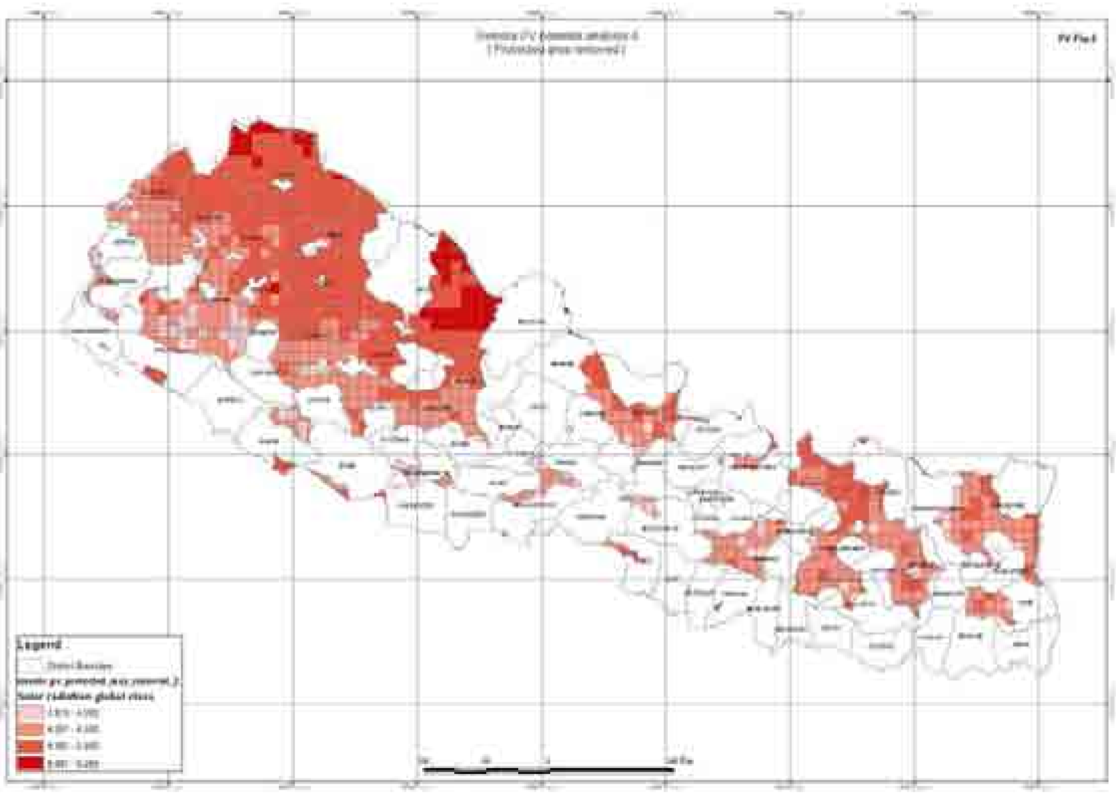
## *ANNEX-2*

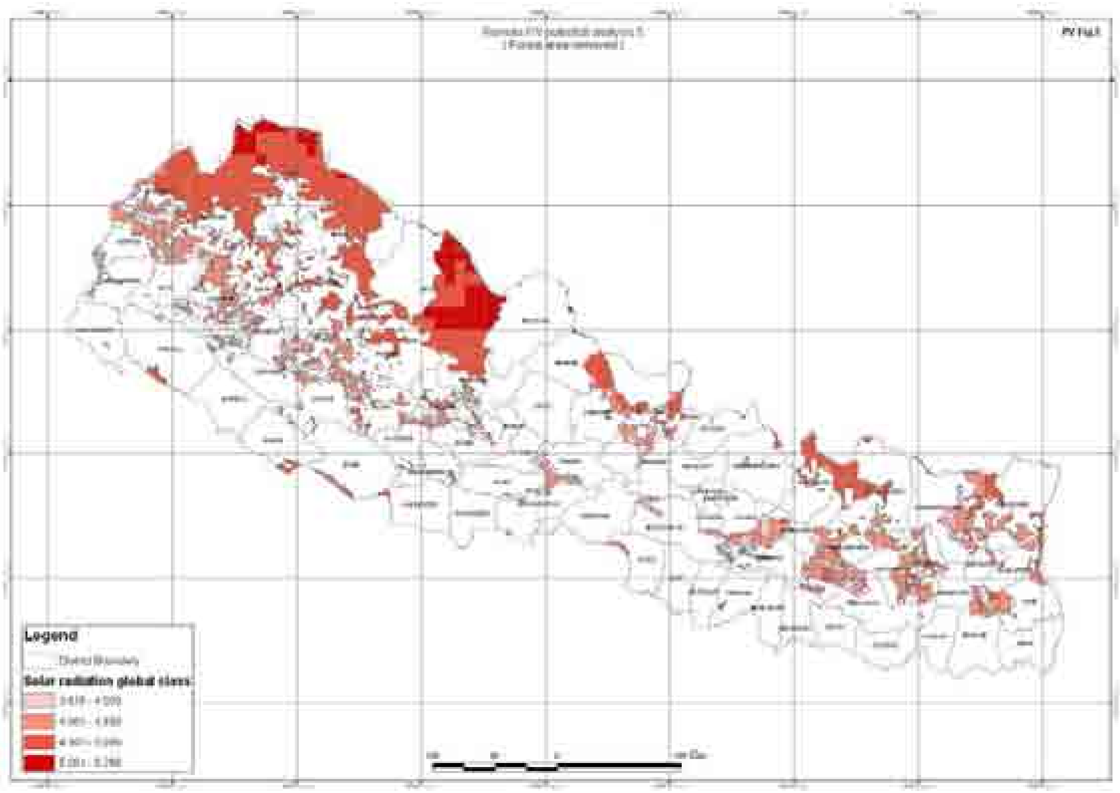
## *(Solar Remote PV Analysis Maps)*

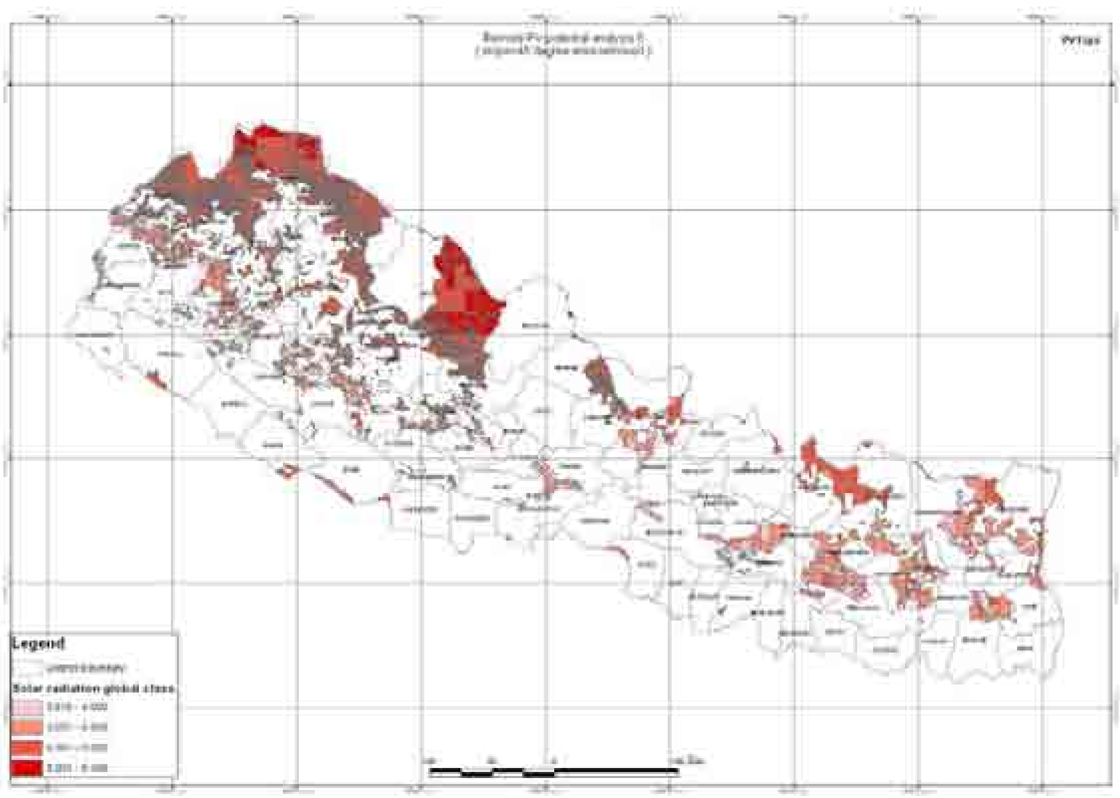

Legend

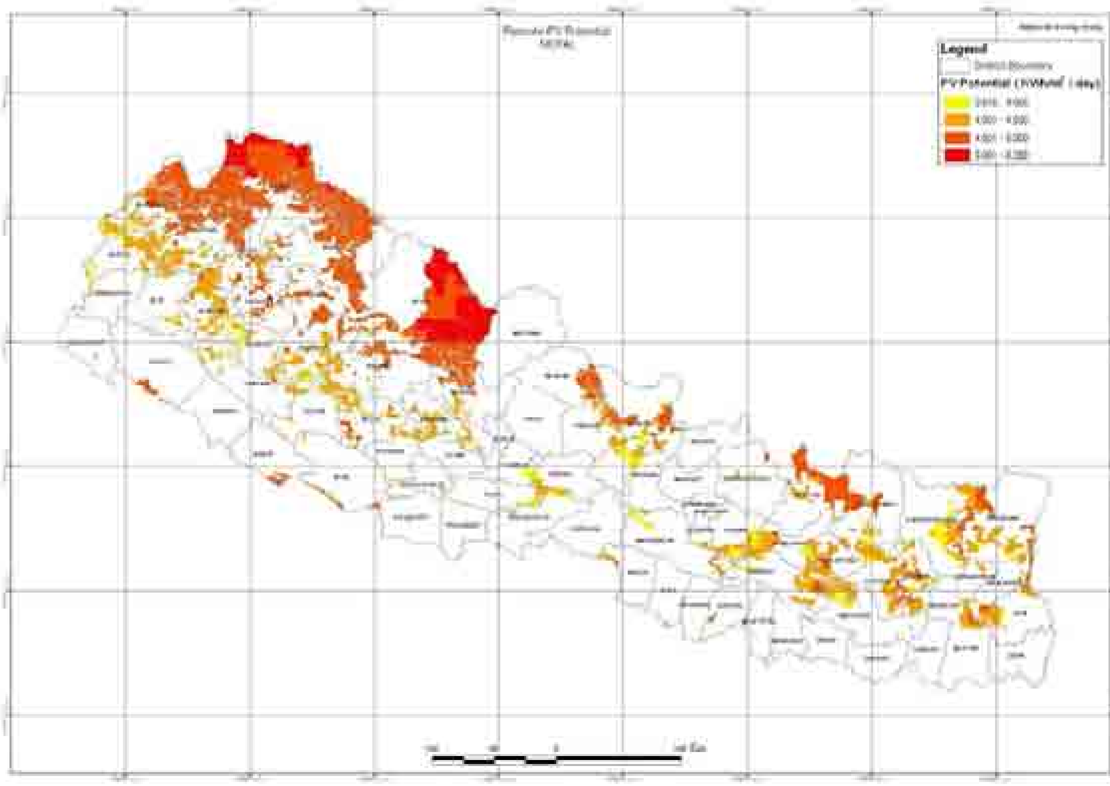

Legend
Solar radiation global class


Legend
Solar radiation global class


Legend

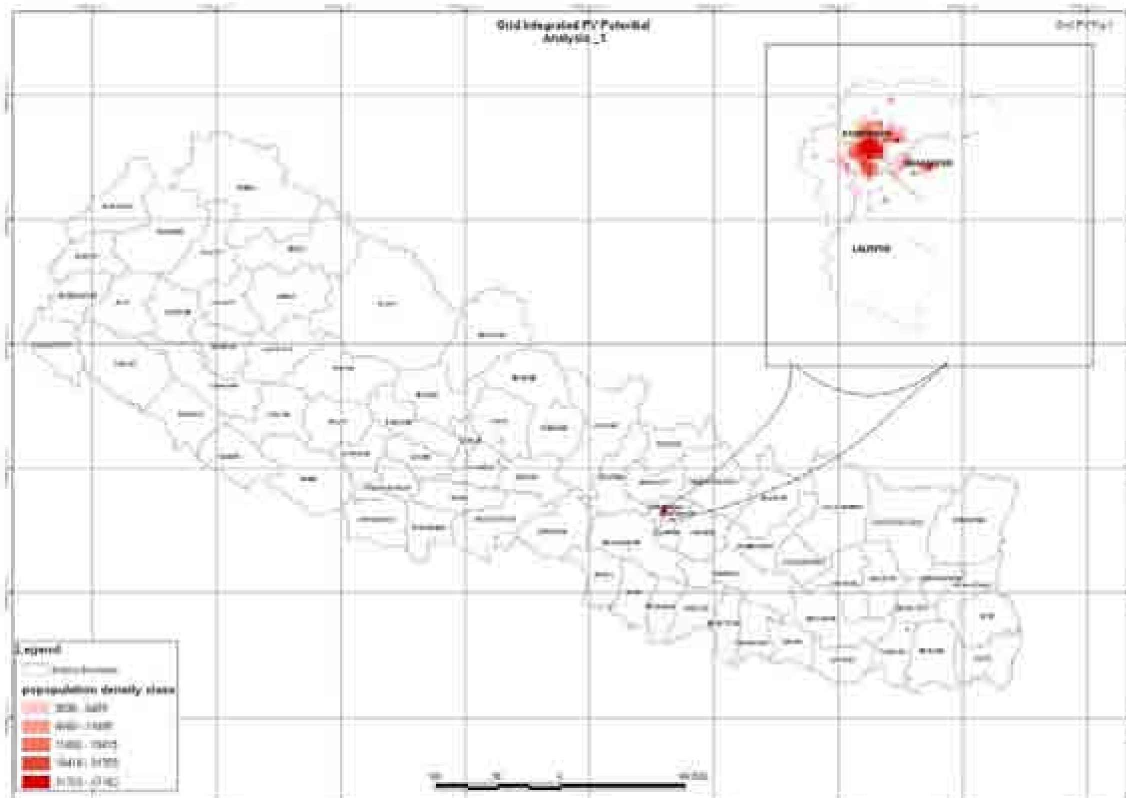

Legend
Solar radiation global class

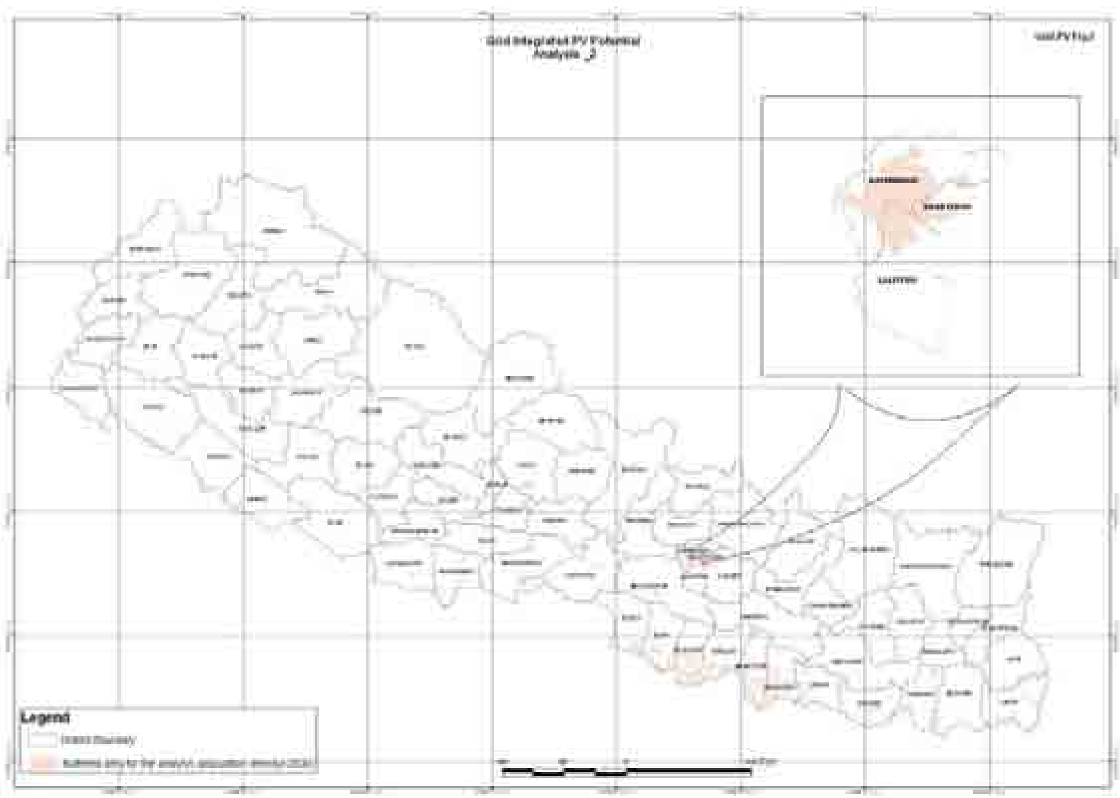

Legend
Solar radiation global class

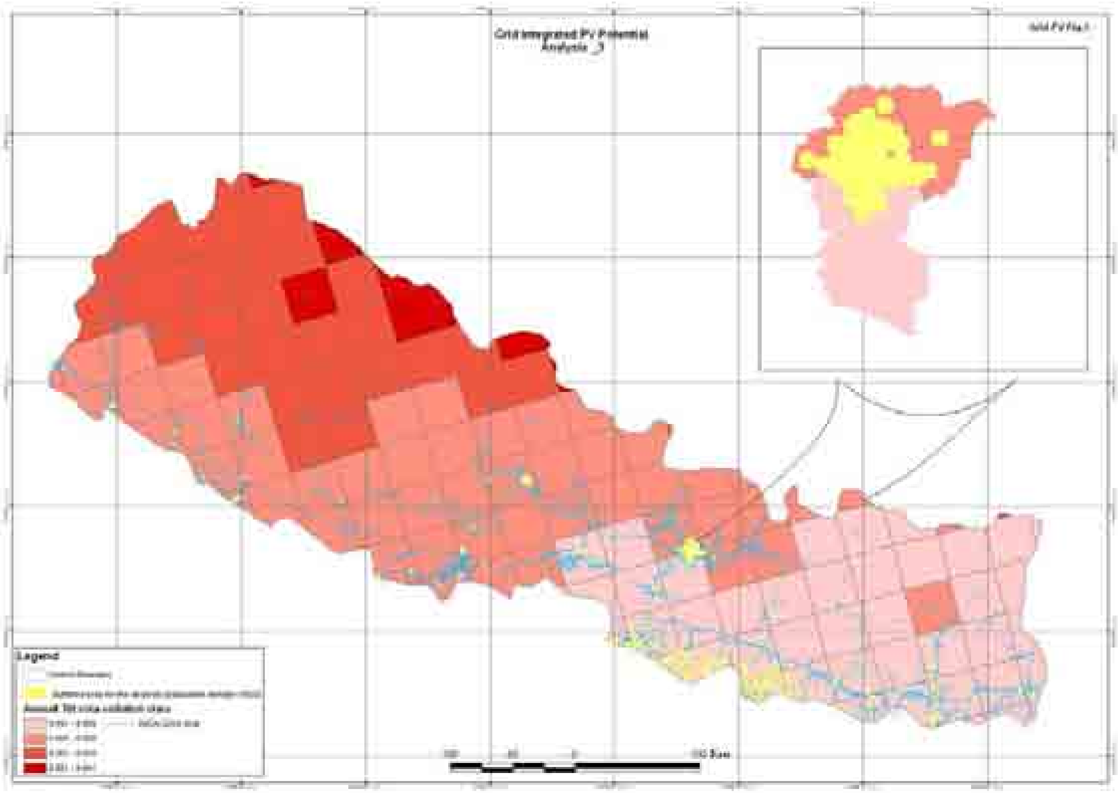

Legend
District Boundary

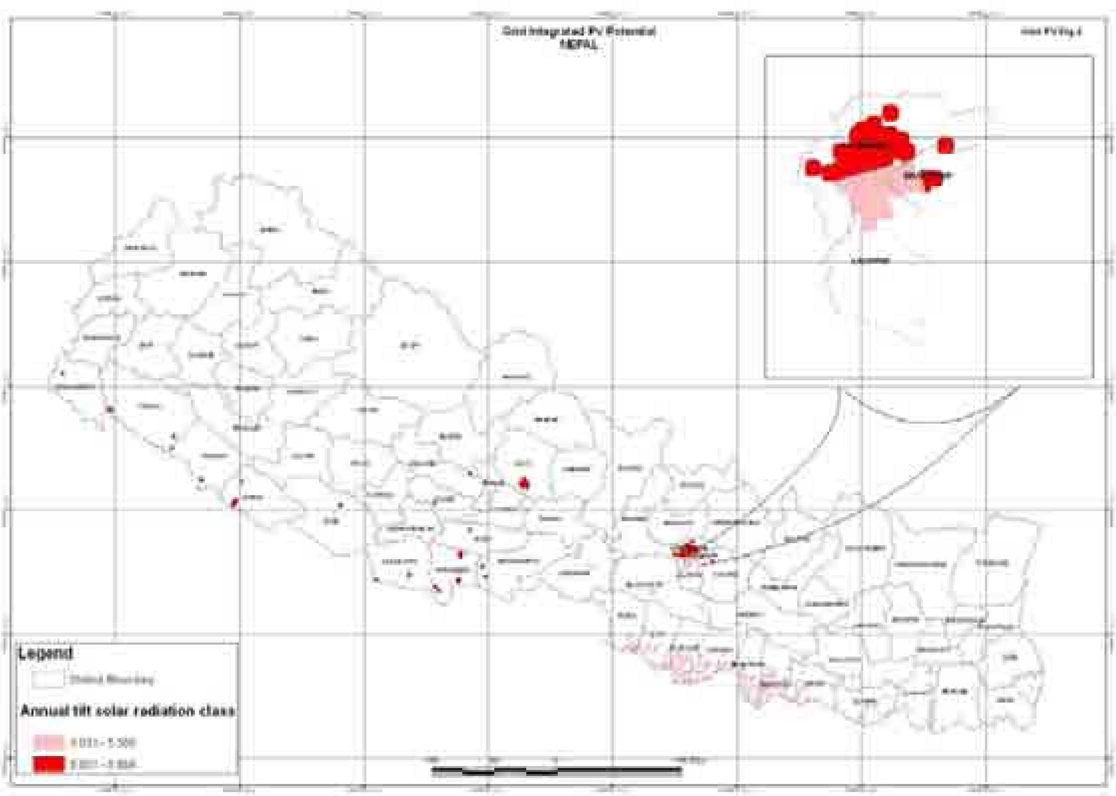
# *ANNEX-3*

## *Solar Grid Connected Integrated PV System Analysis Maps*


Grid Integrated PV Potential
Analysis _1
Legend
popopulation density class

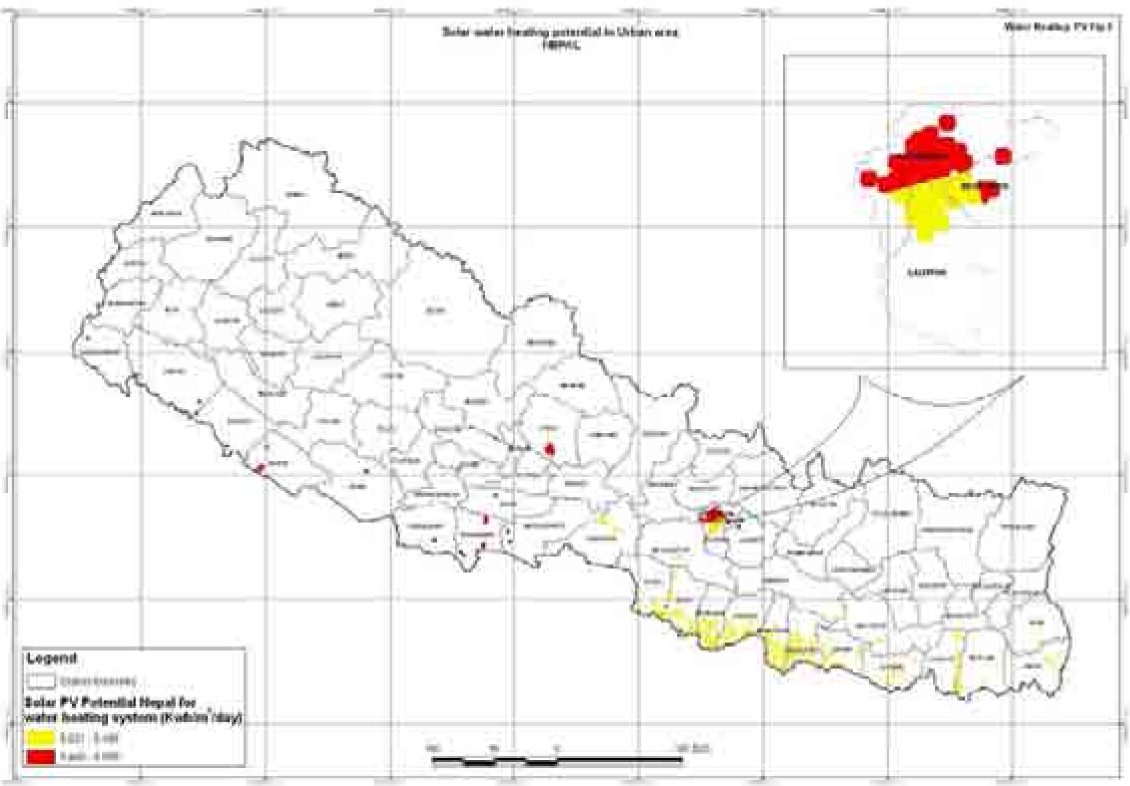

Grid Integrated PV Potential
Analysis _2
Legend


Grid Integrated PV Potential
Analysis _3
Legend


Grid Integrated PV Potential
NEPAL
Legend
Annual tilt solar radiation class

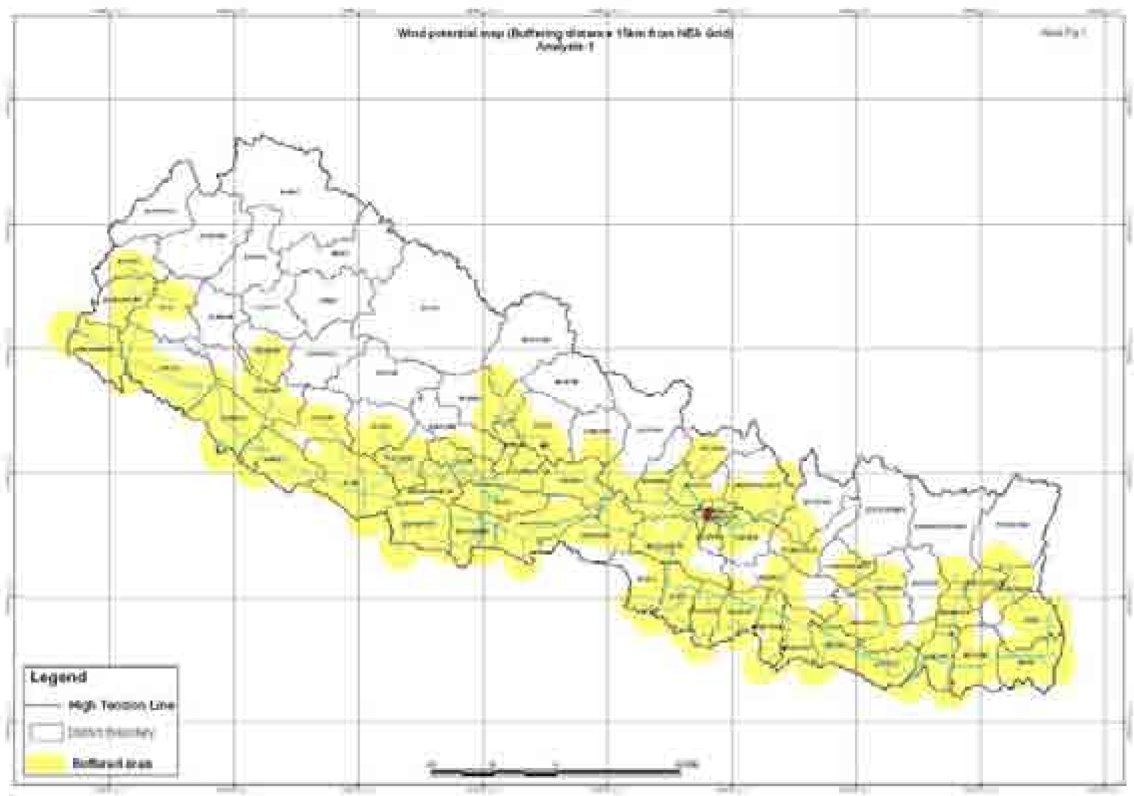
## *ANNEX-4*

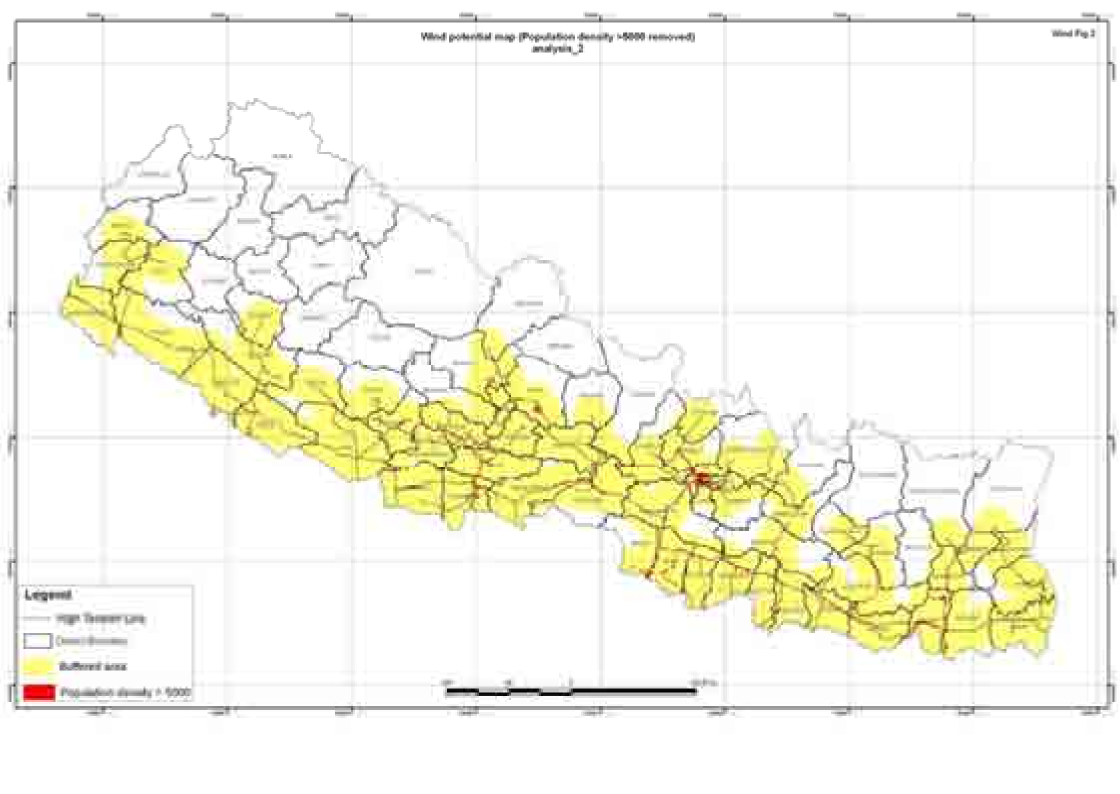
## *Solar Water Heating System Analysis Map*


Solar water heating potential in Urban area
NEPAL
Legend
Solar PV Potential Nepal for
water heating system

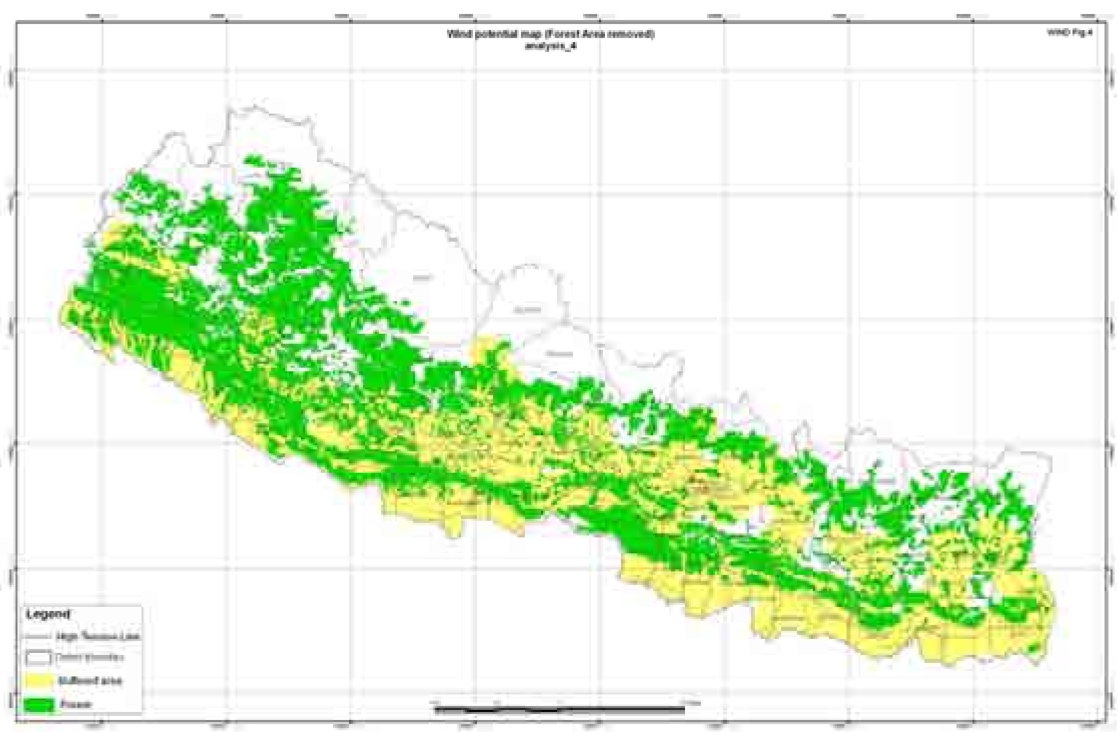
# *ANNEX-5*

## *Wind Energy Potential Analysis Maps*


Wind potential map (Buffering distance 15km from NEA Grid)
Analysis-1
Legend
High Tension Line
District Boundary
Buffered area

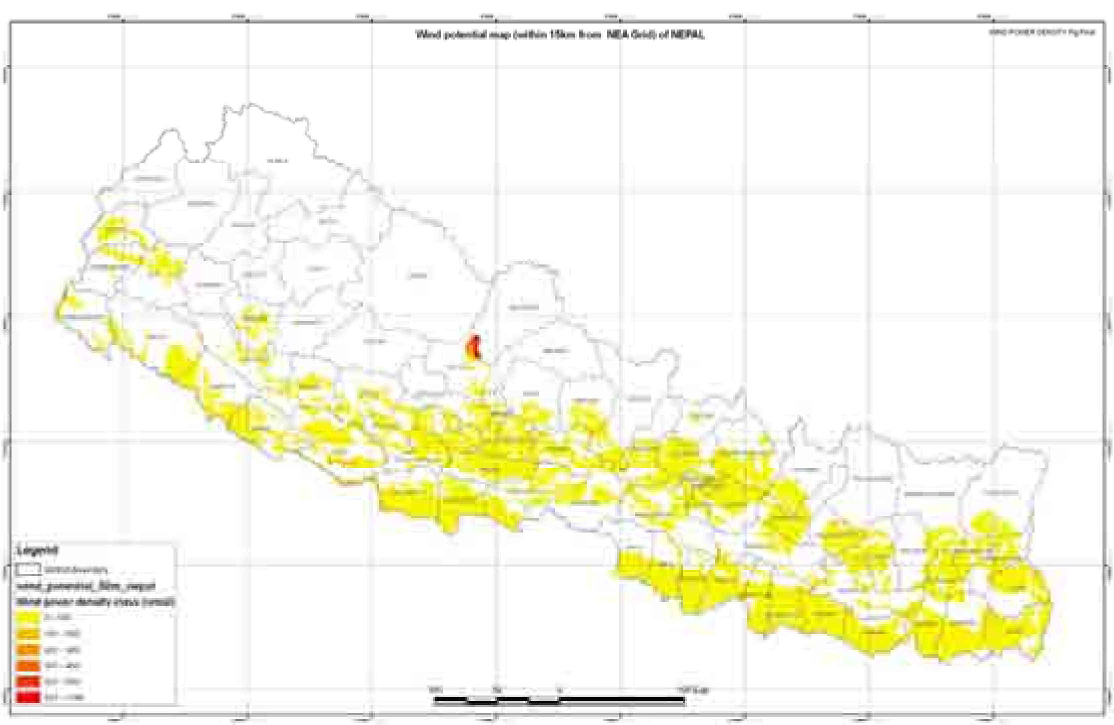

Wind potential map (Population density >5000 removed)
analysis_2
Wind Fig 2
Legend
High Tension Line
District Boundary
Buffered area
Population density > 5000

Wind potential map (Protected Area removed)
analysis_3
Wind Fig.3
Legend

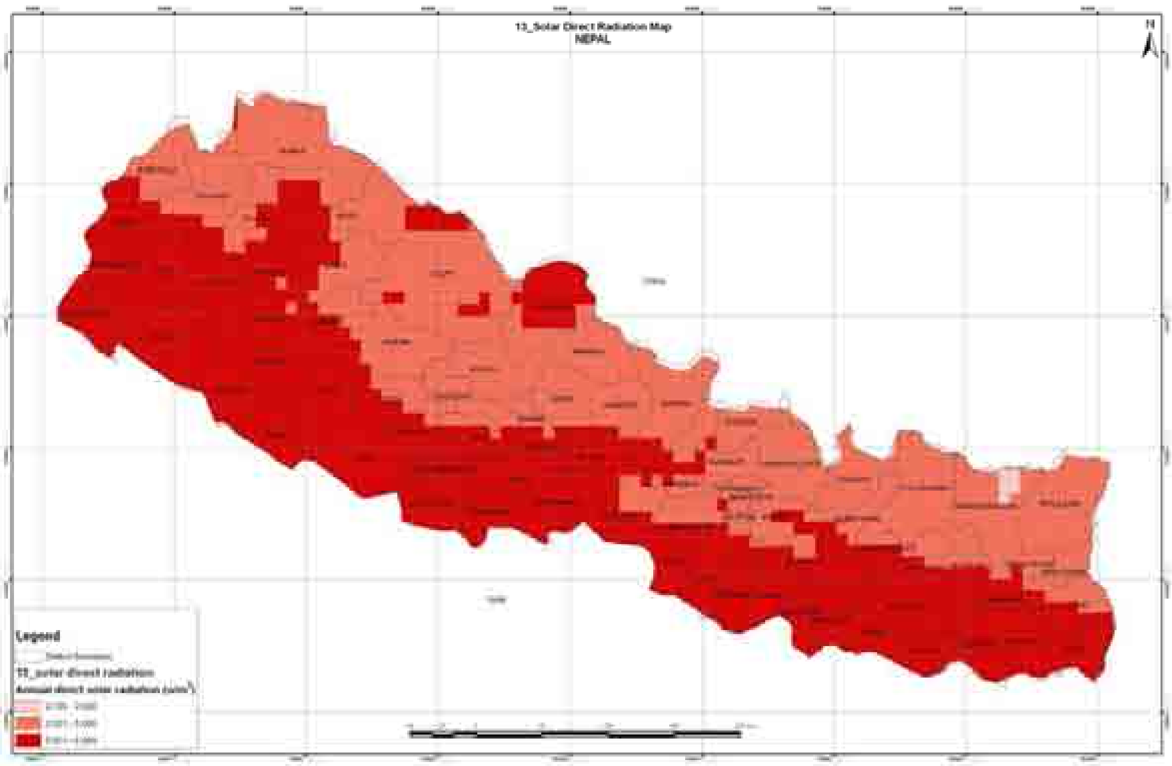
Wind potential map (Forest Area removed)
analysis_4
WIND Fig.4
Legend
High Tension Line
Buffered area
Forest


Wind potential map (Slope > 45 degree area removed)
analysis_5
WIND Fig.5
Legend
High Tension Line
Buffered Area


Wind potential map (within 15km from NEA Grid) of NEPAL
Legend
Wind power density class (w/m2)

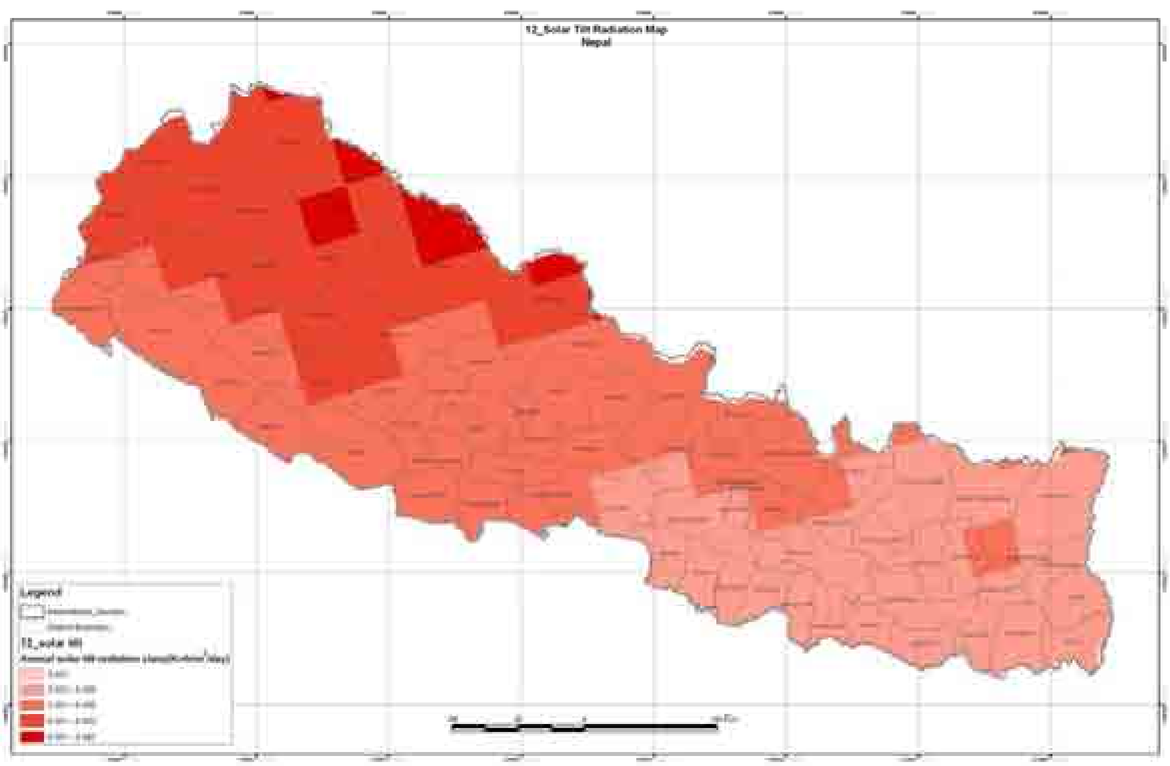
## *ANN-1B*

## *concentrating Solar Power Potential Analysis Base Resource Map*



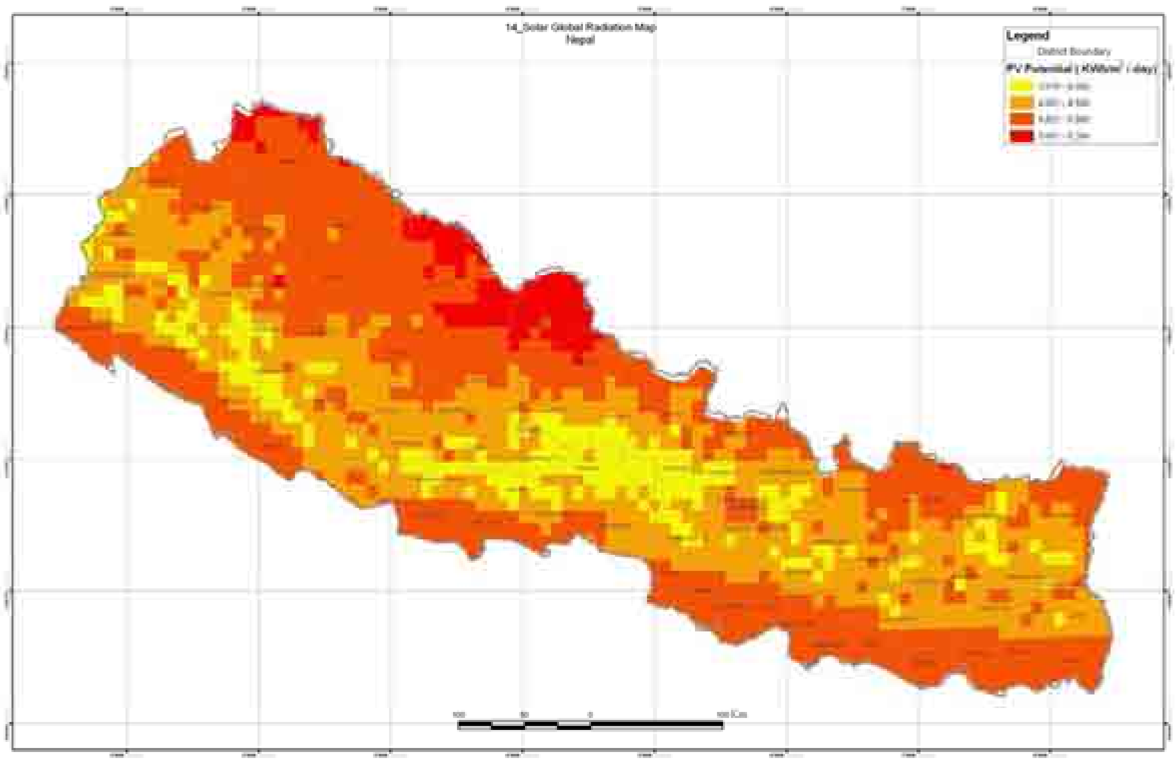
# ANNEX-2B

## *Grid Connected Integrated and Water Heating Potential Analysis Base Resource Map*



## *NNEX-3B*

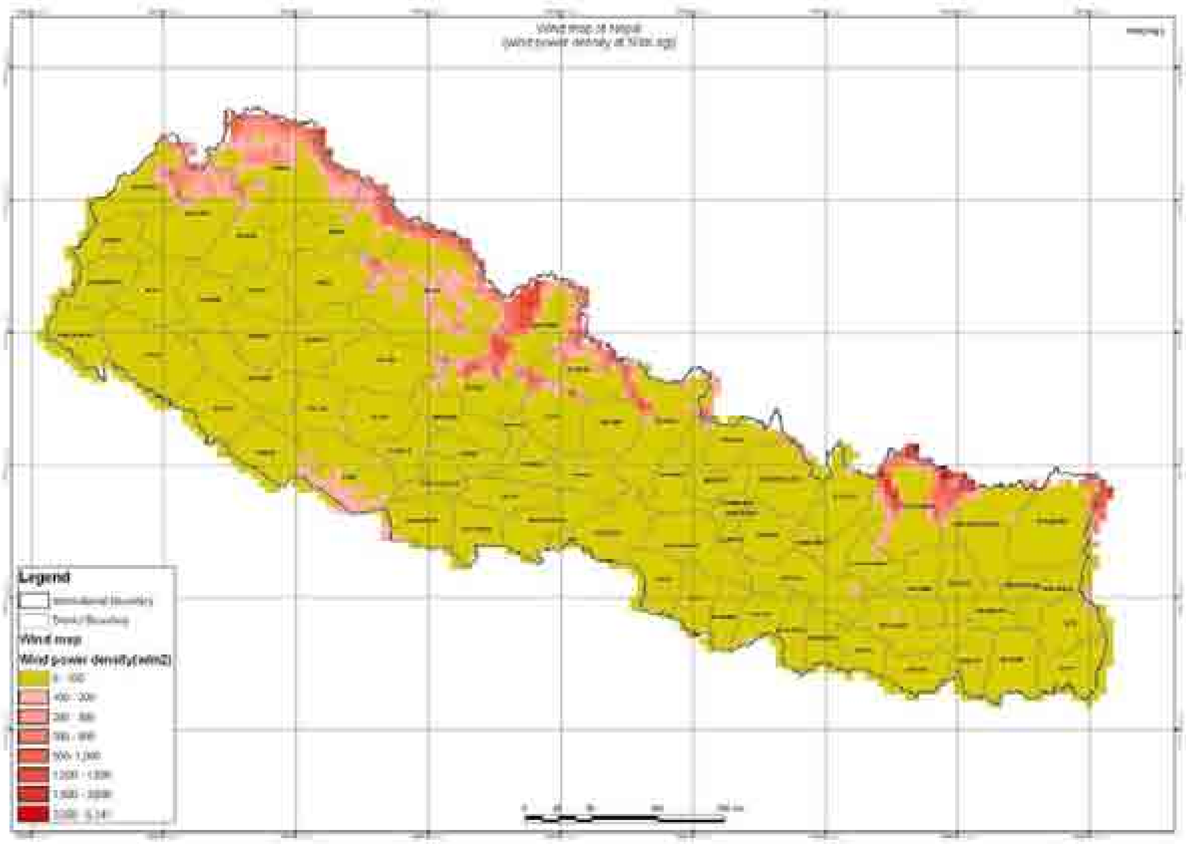
## *Solar Remote PV Potential Analysis Base Resource Map*



## *ANNEX-4B*

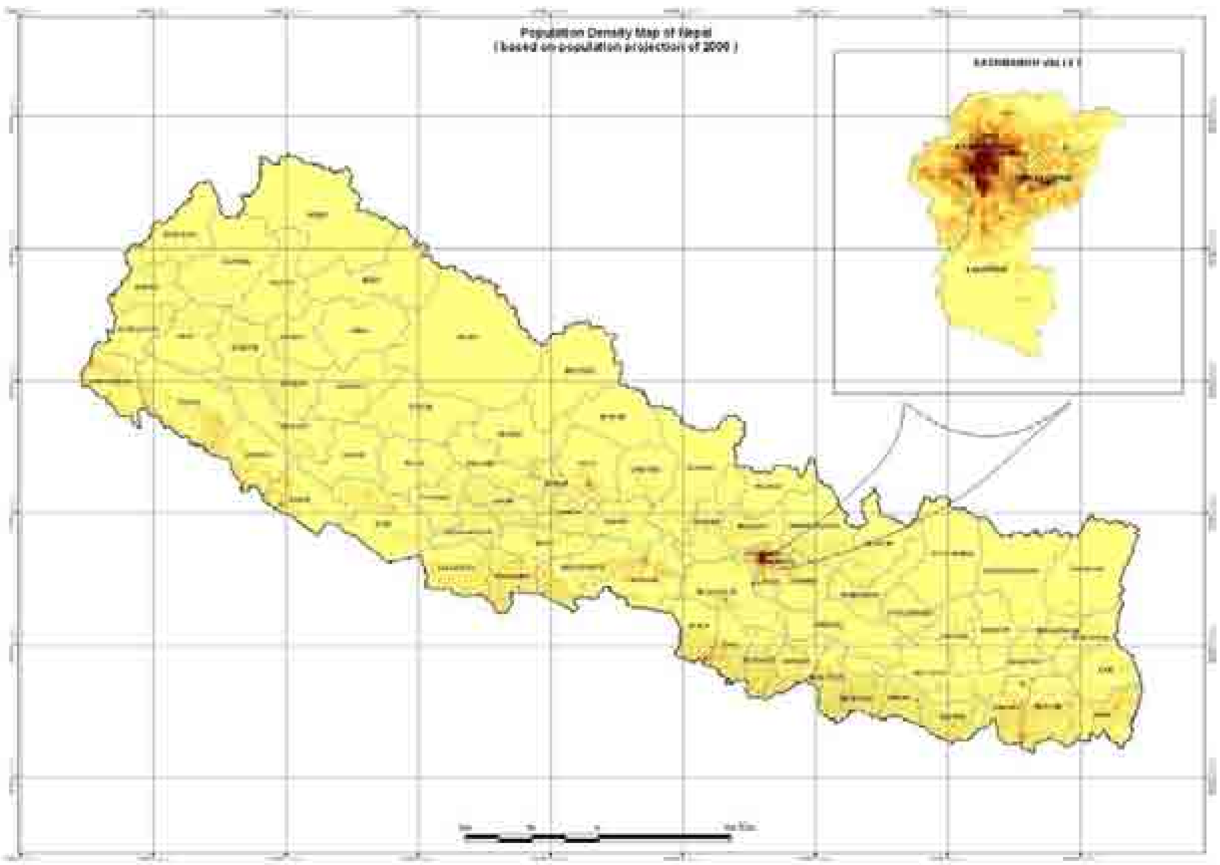
## *Riso Wind Power Density Potential Base Resource Map*

## *( at Above 50m Average Ground Level )*



# ANNEX-5B

# Population Density Map of Nepal



# ANNEX-6B

# Digtial Elevation Model Map of Nepal